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ALPHA EEG ENHANCEMENT: DISCRIMINATION LEARNING, RESPONSE PERSISTENCE TRAINING, AND THE EFFECTS OF DELAYED FEEDBACK

by

© RONALD CURTIS LAYE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ALPHA EEG ENHANCEMENT; DISCRIMINATION LEARNING, RESPONSE PERSISTENCE TRAINING, AND THE EFFECTS OF DELAYED FEEDBACK

submitted by RONALD CURTIS LAYE

in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY.

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DATE AUGUST 12, 1976

DEDICATION

This manuscript is dedicated to my parents, Benjamin and Florence Laye, who provided me with the best. They have been waiting a long time for this.

ABSTRACT

There has been considerable speculation that the biofeedback trained enhancement of electro-encephalographic (EEG) alpha rhythm (8 - 13 Hz) might prove to be a useful tool in relaxation therapy for stress-related disorders as well as a means of personal growth and altered consciousness training. Yet several researchers have recently suggested that alpha increases observed during biofeedback training are due to factors other than the use of feedback information. As well, there has been no experimental confirmation of the learned ability to discriminate levels of alpha in the ongoing EEG. Thus, even an understanding of basic alpha enhancement is currently lacking in the psychological literature.

The present research was designed to study the enhancement and self-regulation of an alpha EEG response. It was specifically aimed at answering four basic questions: (1) Do persons producing increased alpha during biofeedback training do so by using the momentary informational content of the feedback stimulus? (2) Do alpha biofeedback trainees develop an internal feedback loop during training, enabling them to produce enhanced alpha without feedback? (3) Do alpha biofeedback trainees learn to discriminate high from low alpha content in their EEGs? and (4) Would a training

program specifically designed to increase the persistence of enhanced alpha levels actually have that effect?

Twelve volunteers were provided with a continuous feedback tone whose pitch was modulated by the amplitude of right hemisphere alpha. Three one-hour training sessions included feedback trials alternating with probe tasks, which were designed to provide an understanding of alpha enhancement. The probes were an alpha tracking task, an alpha practice task, and a control task, all without feedback, and a delayed feedback probe task. A fourth session provided trainees with either additional feedback training only or in combination with delayed feedback. The persistence of alpha was evaluated in a fifth session. Alpha activity was integrated and standardized within-sessions by average baseline alpha levels.

Results led to the following conclusions: (1) Trainees can enhance alpha by using the immediate information content of the feedback stimulus. Alternative explanations were eliminated by using a within-subjects control procedure involving the unsignalled application of delayed feedback. (2) Trainees develop an endofeedback reference allowing enhanced alpha production in the absence of feedback. (3) Trainees learn to discriminate high from low alpha strength in their EEGs. And (4) the persistence over time of the trained alpha response may be greatly increased by a

training procedure which includes both immediate and delayed feedback trials, as compared with standard training involving only immediate feedback.

While the present research does not address colorful issues, such as the relation between alpha enhancement and therapeutic effect or change of consciousness, it does provide support for the validity of the biofeedback trained alpha enhancement phenomenon itself. Such definitive support for and understanding of basic alpha enhancement has been lacking, and is certainly a necessary precursor to the many interesting applications which have been proposed.

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Introduction

In recent years there has been considerable interest in the use of biofeedback procedures to enhance the alpha rhythm (8-13 Hz) in human electroencephalographic (EEG) activity. In 1962 Joe Kamiya presented a landmark paper in which he stated that persons could learn to discriminate the presence and absence of alpha in ongoing EEG. Several years later, several investigators completed studies (Kamiya, 1968, 1969; Brown, 1970; Nowlis & Kamiya, 1970) which indicated that persons presented with external feedback of their alpha rhythm could learn to regulate the amount of alpha they produced. Biofeedback was becoming a rapidly-growing movement in psychology and health disciplines, offering new techniques for the exploration of psychological process and mind-body relationships and promising significant therapeutic benefit for a wide range of somatic and psychological disorders. Perhaps due to the postulated similarities between states of consciousness produced by alpha biofeedback training and various meditative and contemplative disciplines, alpha biofeedback has ridden the crest of the wave of controversy which has engulfed biofeedback since its beginnings.

Part of this controversy has centered on alpha as a learned response; it has even been suggested that alpha

increases observed during feedback are not the result of learning (Lynch & Paskewitz, 1971). Also, there has been no validation or replication of Kamiya's observations of alpha discrimination. Thus, even an understanding of basic alpha enhancement is not agreed upon in the literature. The present research was designed to study the enhancement and self-regulation of an alpha EEG response. It was aimed at providing satisfactory answers to the following four questions: (1) Do persons producing increased alpha in the biofeedback training situation do so by using the moment-to-moment information available in the feedback stimulus? (2) Do alpha biofeedback trainees learn during their enhancement training to discriminate high from low alpha content in their EEGs? (3) Do alpha biofeedback trainees develop an internal feedback loop during training which would allow them to extend their alpha increases beyond the point at which feedback is withdrawn? and (4) Would a specific training program, designed to increase the persistence of the trained alpha response actually have that effect? The concepts and empirical findings relevant to each of these four issues will be reviewed, establishing a context for the present research undertaking.

Alpha Enhancement and Feedback

There are some basic experimental conditions which affect the definition of the alpha response or the nature of

the enhancement task. Some of these basic issues are electrode placement, eye instructions, quantification of alpha, experimental environment, type of feedback, and arrangement of training trials. These issues are of importance in any alpha biofeedback research. The fact that researchers have selected a variety of combinations of experimental conditions makes it very difficult to meaningfully compare the results of their studies with each other. Since these issues are important, but the present research does not deal with them experimentally, a discussion of them is included in the Appendix.

The early literature was criticized by Lynch and Paskewitz (1971) for a lack of experimental control for various extraneous experimental and natural effects. Factors named by them and others as confounding the interpretation of alpha biofeedback research include enhanced alpha due to: (a) naturally rising baseline, (b) evocative effects of the stimulus situation, (c) instructional effects, and (d) motivational level and subject-experimenter interactions. These factors will be discussed in order.

Rising baseline alpha activity, that is, progressively increased amounts of alpha manifesting during rest periods between feedback training trials, plagued early alpha researchers. Kamiya (1969) obtained resting alpha levels

nearly identical to the enhanced levels with feedback, and interpreted this as evidence that subjects preferred their newly-acquired elevated levels of alpha. Hart (1968) also noted that subjects not provided with direct feedback produced progressively increased alpha during sessions. Lynch and Paskewitz (1971) suggested that any initial alpha baseline would likely be depressed by apprehensions about the novel situation, and would recover with habituation to the setting. Thus, unless baseline is recorded at least at the beginning and at the end of a session, there is no way to separate the possible effects of genuinely learned alpha enhancement from rising baseline activity.

Lynch and Paskewitz (1971) have suggested that alpha increases observed during biofeedback training were the result of disinhibition of those influences which block the normal production of alpha. Optimal baseline alpha level, recorded with eyes closed in the dark, is depressed when a person attends to his surrounds; the biofeedback trainee does nothing more than become less attentive to his environment as he adjusts to the novel situation. In a later study, Lynch, Paskewitz, and Orne (1974) found that there was no difference in alpha generated over trials for subjects receiving contingent versus noncontingent feedback signals. Both groups demonstrated significant linear increases over trials, and the patterns appear almost identical, as noted by the authors. They remarked that

"alpha densities observed in the feedback situation have less to do with feedback per se or a learning process than with the situation and Ss' own natural alpha densities" (p. 399). Thus, the straightforward interpretation of alpha enhancement as the effect of learning due to information present in the feedback stimulus was seriously questioned. It was postulated that the disinhibition of factors that block alpha could account for biofeedback produced alpha enhancement and for the similar enhancement produced by subjects receiving no or noncontingent feedback.

While attentional factors are usually thought of as being capable of blocking alpha activity, Morrell (1966) identified situations in which alpha could be induced by stimulus situations. Mulholland and Evans (1966) provided evidence for the involvement of the oculomotor system in eliciting differential amounts of alpha. Evidence that the feedback tone itself can evoke increased amounts of alpha was given by Selzer and Fehmi (1975), who were successful in driving alpha with rhythmic auditory signals resembling feedback. While this result has not been substantiated for actual feedback signals themselves, even slight alpha increases produced in this manner could lead to alpha strength reaching and remaining at maximum level, through the operation of a positive feedback system. Additional evidence suggesting a possible evocative effect of feedback was provided by Travis, Kondo, and Knott (1974a), who found

that yoked control subjects receiving feedback generated by paired experimental subjects increased their alpha significantly more than a group not receiving feedback at all, but less than the experimental subjects. A ready interpretation is that the enhancement produced by the yoked subjects was due to evocative and other uncontrolled effects, while additional enhancement produced by experimental subjects was due to learning. The enhancement shown by the Lynch et al. (1974) subjects receiving noncontingent feedback could be interpreted as being due to evocative effects as well as disinhibition. Thus, the feedback signal itself and perhaps other components of the experimental setting may be capable of leading to enhanced alpha activity which could be mistaken for learning. This possibility must be controlled for if one wishes to claim that learning has occurred in the biofeedback situation; that is, that enhancement is due to the subjects' use of informaticnal content of the feedback signal.

A third and very sensitive issue in alpha research has been the effect of instructional set upon enhancement performance. Beatty (1972) provided subjects with either feedback alone, instructions alone, or both feedback and instructions. He found that all three groups did equally well at enhancing alpha, and did significantly better than control groups receiving no-feedback or inappropriate instructions. In a more comprehensive study, Plotkin

(1976a) found that oculomotor instructions emphasizing a blurring of focus could produce significantly increased alpha strength, and that subjects receiving both cculomotor instructions and proportional feedback showed the greatest enhancement. Rouse, Peterson, and Shapiro (1975), like Beatty, found that the effects of short-term feedback depended completely upon instructional set. Thus, it appears that at least a significant part of the enhancement produced by subjects in some biofeedback training situations may be due to the nature of the instructions.

In most human performance research, including biofeedback, the interaction between the subjects and the experimenter and motivational levels of the subjects must be considered. The subject-experimenter interaction has been thoroughly reveiwed by Rosenthal and his colleagues (Rosenthal & Rosnow, 1969). Important components of this interpersonal interaction include the subject's desires to please the experimenter, to be judged positively, to confirm or disconfirm experimental hypotheses, and to ccoperate or resist. Experimenter behaviors and manner, subject sophistication in psychology, and consequences of participation can all affect motivational and cognitive components of the experimental participation. When these effects are collectively considered, the importance of experimental control through double-blind assignment of subjects to groups or through within-subject procedures must

become a strong consideration.

There is some evidence from biofeedback experiments establishing the importance of motivational level for performance. Kondo, Travis, and Knott (1975) have demonstrated that paid research subjects given a five or ten dollar bonus for a certain level of alpha enhancement produced more alpha during feedback training than did subjects receiving no bonus. Also, Valle and Levine (1975) have conducted research in which subjects were informed that they would be increasing or decreasing their alpha levels. The subjects were then given feedback for either increased or decreased alpha (a 2 x 2 design). Subjects who had been led to believe that they would be increasing alpha did better at both increase and decrease tasks, which may be interpreted as an increased motivational effect on performance for subjects who believed they would be increasing alpha (desirable task). Thus, motivational effects can be potentiated either by directly providing extrinsic reinforcers, or by creating expectancies concerning positively-valenced tasks.

The most solid support for the effectiveness of the informational content of the feedback stimulus in leading to enhanced alpha comes from studies by Travis et al. (1974a) and Plotkin (1976a). Travis and his colleagues investigated eyes-open alpha enhancement, employing an experimental

group, a yoked-control group, and a no-feedback control group. Subjects received six ten-minute practice sessions on each of two days, the experimental and yoked subjects being paired and run simultaneously. Alpha was measured as per-cent time above a non-arbitrary, individually determined threshhold, and feedback was provided by the binary state (off/on) of a lamp. Results from Day 1 indicated that the experimental group emitted more criterion alpha than either control group, and that the yoked-control group produced more alpha than the no-feedback group. On Day 2 of the experiment, the previously yoked subjects received genuine feedback, and performance reached the level of the experimental group. One disturbing result was that the amount of alpha increase over trials appears to have been approximately equal for the experimental and yoked control groups. The difference between experimental and control subjects' enhancement was confounded by differences in initial baseline. A follow-up involving several additional subjects revealed a difference independent (most likely) of original baseline, but the difference between experimental and yoked groups was due to the first two or three minutes of training trials. While this does not negate the results, the authors themselves noted that "the performance curves do not resemble typical acquisition curves found in the development of conditioned responses" (p. 173). Other studies (Cleeland, Booker, & Hosokawa, 1971; Strayer, 1970)

with less adequate methodologies than the Travis et al. study employed control subjects yoked in an off-line manner (receiving feedback taped from experimental subjects), and reported no significant differences between experimental and control subjects.

Plotkin's (1976a) study of alpha enhancement provided subjects with either feedback or no feedback plus oculomotor, cognitive, or no instructions. Subjects were run in sessions with both lights on and off, and had enhance, suppress, and rest trials within sessions. The chief result of interest here is that subjects receiving feedback did significantly better than those receiving no feedback, and this result was strongest for the lights-on sessions. Also, only subjects receiving feedback showed trial-to-trial increases in alpha. Oculomotor instructions were superior to cognitive instructions, but only with the lights on, and oculomotor instructions alone (but not cognitive instructions) were equal to feedback alone in producing enhanced alpha. The feedback plus oculomotor instructions produced the greatest alpha enhancement.

Plotkin's study reasonably well demonstrates the effectiveness of the feedback stimulus in producing increased alpha. That it was the informational content rather than the evocative effects could be supported more strongly if there had been a group of subjects receiving

noncontingent feedback, in addition to a no-feedback control. Also of concern is that the amount of enhancement was not very large. The feedback plus oculomotor instructions group, producing the most enhancement, had a mean alpha strength of 24.9% greater than baseline level. Hardt and Kamiya (1976b) attributed the low enhancement levels to the nature of the eyes-open plus lighted room conditions, which were said to insure that Plotkin would be studying the recovery of alpha to normal baseline level rather than learning per se. There is as yet no strong evidence concerning what part learning, that is, the use of feedback information, plays in alpha enhancement produced during non-extensive (less than two hours) biofeedback training.

The present study is concerned with assessing the effect of the informational content of the feedback stimulus, apart from all other factors, in producing enhanced alpha during biofeedback training. A within-subjects control procedure is employed, which eliminates effects of rising baseline and disinhibition, alpha evoked by experimental conditions, differential instructions, and motivational and social psychological variables. experimental situation. The technique employed involves the insertion of training trials with a feedback signal delay of nine seconds between regular biofeedback training trials. Delayed feedback trials are not detected as being different

by subjects (as discovered during pilot research). They resemble regular immediate feedback completely except for the temporal correspondence between EEG and feedback signal. Thus, if subjects who show alpha enhancement during regular feedback suffer a significant drop in performance during delayed feedback, and then recover to former levels of enhanced alpha during subsequent regular feedback trials, evidence is provided for the effect of informational content of the feedback, apart from other factors, in producing alpha enhancement.

Alpha Discrimination

Although research in the self-regulation of alpha was born largely from Kamiya's (1962) study of alpha discrimination, the literature still contains no controlled study verifying the alpha discrimination phenomenon. Yet it is often assumed that learned control of physiological activity is based upon successfully discriminating different levels of the relevant activity. Kamiya (1974) suggested that "subjects should be trained to a high degree of control of the physiological measure to strengthen their discriminative grasp of the ability involved" (p. 36). Budzynski (1973) included increased awareness of physiological activity, as distinct from control of it, as a goal of biofeedback training in therapy. This assumption of discriminative ability certainly follows in a

straightforward manner from learning theory; control implies discrimination because a correct response must be based upon correct discrimination of the alternatives. If, however, alpha increases during biofeedback training were, as suggested by Lynch, et al. (1974), not due to learning, apparent control of physiological activity might manifest without discriminative ability. Or possibly, as they report in their research, perfect differential control, which they accept as evidence for discrimination ability, would be evidenced at the outset of training, rather than be gradually acquired as is usual in discrimination learning. Thus, while a demonstration that persons who learn to control their alpha also gain discriminative ability gradually would not prove that alpha control was a learned phenomenon, it would make that interpretation considerably more plausible.

Kamiya's (1962) discrimination research was based upon a simple discrimination learning design. Subjects were connected to EEG monitoring equipment (occipital monopolar placement), and the EEG tracing was observed by the experimenter, who rang a bell during randomized alpha and no-alpha periods in the EEG. The subjects called out their guesses (A or B), and were then given verbal feedback (correct or incorrect). Performance on this task progressed from essentially chance levels during the first hour to at least 80% correct for all subjects after 50 to 500 trials.

Some subjects achieved 100% scores. These results are certainly impressive, but must remain suggestive due to only minimal controls. Interactions between the experimenter and the subjects, selection of alpha and no-alpha periods, and timing of bell-rings might have contributed in some way to the obtained results.

Legewie (1975) attempted to verify Kamiya's alpha discrimination results, and used a similar discrete-trials discrimination learning paradigm plus rigorous methodological controls to rule out potential extraneous factors. A lab computer selected brief intervals from ongoing EEG and presented an audible tone to the subject, who was then to estimate his EEG activity preceeding the tone. In one part of the study the subjects responded by adjusting the position of a lighted cross in a two-dimensional computer display screen. The response was followed by a dot plotted by the computer, representing the actual EEG activity. The two axes represented period and amplitude of the EEG. Duration of the criterion EEG periods and amount and spacing of training trials was varied among six subjects, each of whom was considered a separate experiment. Subjects received between 150 and 800 trials, all with feedback. Results indicated that no discriminative ability was gained during the training; even after training, there was no better than chance association between estimated and actual EEG states.

In order to conform with Kamiya's binary choice task as a measure of and technique for training discrimination, Legewie simplified the task for three additional subjects, requiring a binary button-push to indicate alpha and no-alpha. Two of the subjects, receiving 400 and 800 trials, respectively achieved significant hit rates of 58% and 55%. There was, however, no significant increase in accuracy over trials (trend analysis), suggesting that a discrimination was not learned over training. A further study reported in the same paper confirmed the results and also evidenced no difference in discrimination ability between subjects who had received genuine versus random feedback. Legewie suggested that the negative findings may have been due to his arbitrary experimental conditions, such as having selected brief EEG intervals as the object of discrimination, and having selected eyes-closed occipital EEG. It is possible, as noted by Legewie, that experimental conditions precluded obtaining positive results. If it is true that substantial cognitive states are associated with changes in alpha activity (Brown, 1971; Kamiya, 1974), then the two to four second criterion period may have been too brief to allow for the necessary discrimination. Hardt (1975a) suggested that the essential difference between Kamiya's and Legewie's results was due to Kamiya's warm personal approach versus Legewie's impersonal computer; Kamiya's approach may have allowed subjects to produce more

variability in their alpha patterns, thereby making the discrimination task an easier one.

Another possible explanation for Legewie's failure to obtain alpha discrimination is that the simple discrimination task is more complex, from the subject's point of view, than it seems. First there is a signal-to-respond, to which the subject must orient. This orienting may be evident cognitively as well as in physiological reactivity, including transient EEG response. The orienting response may change (habituate) over trials. Next, the subject must recall his activity preceeding the signal-to-respond. It is certainly possible that the orienting and/or the storage required in the discrete-trials discrimination learning paradigm might interfere with the delicate task itself, either by limiting the variability of the parameter, as suggested by Hardt (1975a), or by requiring a level of information processing which is incompatible with discrimination ability itself. Additionally, when the test trials are not distinct from the training trials, the processing of the post-trials feedback might also complicate the task. This analysis applies to both Legewie's and Kamiya's research, but may have operated differentially to have allowed less restricted variability of EEG and less interference due to timing of trials and duration of criterion intervals in Kamiya's work. This analysis must remain speculative, but would suggest that some method other

than a discrete-trials training approach for testing or training alpha discrimination might have a better likelihood of obtaining successful discrimination.

The term "alpha discrimination" has been used to denote something other than the recognition of alpha in the EEG, as in the research of Kamiya and Legewie. Brown (1970) used the term to refer to the difference between alpha abundance during enhancement training trials (with feedback) and adjacent rest trials (no feedback). Plotkin's (1966a) discrimination score was based on a difference between alpha during enhancement and suppression trials, both with feedback. Both Brown's and Plotkin's definitions of alpha discrimination are operationally based upon performance during feedback trials. Such an interpretation, therefore, leaves no clear distinction between discrimination and control of alpha. Since the two can be separated theoretically and experimentally, there is a definite gain in limiting the defining circumstances for the discrimination of a physiological activity to experimental situations allowing for the recognition of the physiological activity without the presence of an external (feedback) signal providing information upon which a successful discrimination could be made (that is, by discriminating levels of the feedback signal rather than the physiological activity itself). This allows for a test of the common assumption that control implies discrimination. That is,

subjects could be trained to control a physiological parameter, and then be required to make discriminations. If such discrimination was not obtained, with alpha for example, then there would be strong reason to suspect that there was no true learning occurring, and that perhaps, as suggested by Lynch et al. (1974), there was simply a disinhibition of activity which blocks alpha. This is what makes the absence from the literature of well-controlled successful alpha discrimination somewhat disconcerting.

Because there is little research pertaining to alpha discrimination, discrimination research employing other physiological parameters will be summarized. The evidence for learned heart rate (HR) discrimination, and for the relationship between discrimination and HR control, is more definitive than for any other physiological activity. Early research attempted to relate autonomic perception, as defined by scores obtained on the Autonomic Perception Questionnaire (APQ), to HR control. Partial support of such a relation was reported by Bergman and Johnson (1971), who found that the best control was obtained by subjects who had intermediate scores on the APQ. Two subsequent studies (Bergman & Johnson, 1972; Blanchard, Young, & McLeod, 1972) failed to confirm a relationship between APQ and HR control scores. The latter studies used instrumented (biofeedback) HR control training, while the former assessed untrained control ability.

Since it should be important that successful control be accompanied by discrimination ability (Brener, 1974a), a more valid behavioral measure of HR discrimination was sought. Brener and Jones (1974) presented subjects with brief vibratory stimulus trains which were either contingent or noncontingent on heart beats. Subjects who had received accurate information as to the correctness of their choices improved significantly from pre- to post-training, while control groups did not. Additional evidence that HR discrimination could be trained was provided by Epstein and Stein (1974), who found that subjects could be trained to discriminate between heart rates higher and lower than previously assessed mean levels. Furthermore, some discriminative ability greater than pretraining baseline was retained after feedback had been withdrawn only in the experimental group.

Heart rate discrimination was related to learned self-regulation in studies by McFarland (1975), Brener (1974b), and Clemens and MacDonald (1975). McFarland required subjects to attempt to track their HRs by button-pressing for each perceived beat. The tracking test, without feedback, was followed by feedback-assisted increase and decrease HR trials. Results revealed that subjects who achieved high tracking scores also increased HR significantly better than others, while there was no

difference on the HR decrease task. Brener found that subjects trained first to discriminate HR did better in HR control than did subjects not given discrimination training. Clemens and MacDonald found that prior HR discrimination training facilitated feedback-assisted but not non-instrumented HR increase performance. Thus, there exists sufficient evidence linking HR discrimination and control abilities.

With the exception of HR, there is no body of literature which reasonably explores discrimination of physiological activity. There are some reports worthy of mention. Lovibond and Caddy (1970) and Silverstein, Nathan, and Taylor (1974) have found that persons could be trained to discriminate different levels of alcohol concentration in the blood. Stern (1972) found that subjects could detect spontaneous changes in the GSR, but Diekhoff (1976) has questioned the interpretation of such results. Staudenmayer and Kinsman (1976a) provided evidence suggesting that persons receiving frontalis muscle EMG feedback training are better able to make accurate post-trial binary assessments of their EMG level during the trial. Since feedback was present during the trials, however, it is unclear whether subjects were basing their judgments upon perceived EMG levels or the amount and level of feedback received.

While it may be informative to study the literature

relating to discrimination of activity other than EEG alpha, the results from these studies are only suggestive with respect to alpha. Heart rate is a clearly more familiar and more commonly discriminable event than is alpha for most people. Everyone is familiar with the feeling of the heart beat, as detected by a hand on the chest or a stethescope. Also, many people are familiar with an increased HR which accompanies an overall ergotropic response in the body preparing to meet real or perceived danger. Such familiarity with EEG responses would be almost universally denied. Alpha remains an elusive response, and it seems reasonable to assume that training for its discrimination would start essentially from scratch.

The present research is designed to study the performance of subjects on an alpha discrimination task at a series of intervals over alpha biofeedback training. In order to eliminate the problems which may be inherent in a discrete-trials discrimination learning or assessment approach, a binary tracking task will be used as a measure of discrimination. Subjects will not receive feedback for their discrimination performance; instead, it is expected that the training in self-regulation of alpha will provide the ability to progressively increase discrimination ability.

Endofeedback Loop

It is usually assumed that biofeedback training imparts a skill, that of self-regulation of an internal variable. The subject might first attend to the feedback stimulus and become aware of some internal state which exists when the feedback indicates the appropriate change in the critical variable. The trainee might then try to control the feedback signal, and hence his physiology, by recapturing that internal state. Whether the internal state is itself direct experience of the critical variable or is correlated with it or a mediator of it is an interesting question beyond the focus of the present discussion. A simple description, however, of biofeedback trainees' ability to produce alpha independent of the presence of the feedback signal, in that this would require the presence of an internal feference signal, is a useful validation of the notion of endofeedback loop.

Evidence that persons trained to enhance alpha could subsequently do such independent of the feedback signal was provided by Travis, et al. (1974a), who included a ten-minute no-feedback trial immediately after five ten-minute training trials on each of two days. They found that subjects did not show performance reductions with the withdrawal of feedback, though with per-cent time measures of alpha, it is not possible to examine possible amplitude

changes. Subjects informed that feedback was being withdrawn produced significantly more alpha without feedback than did uninformed subjects.

In a study comparing continuous biofeedback to discrete verbal feedback in frontalis muscle EMG training, Kinsman, O'Banion, Robinson, and Staudenmayer (1975) found that while both forms of feedback facilitated muscle relaxation, only continuous biofeedback transferred control to no-feedback trials. In a recent study, Staudenmayer and Kinsman (1976b) found that subjects given EMG biofeedback training were more accurately able to identify levels of EMG activity in the absence of feedback. These studies provide evidence for an internal feedback mechanism, involving the awareness of some internal stimulus or event which allows one to recognize and produce different levels of EMG activity in the frontalis muscle.

The present research charts the development of the ability to produce alpha in a no-feedback condition inserted at a number of points during biofeedback training. It is expected that alpha strength in the no-feedback condition will increase progressively with biofeedback training.

Persistence

Persistence may be generally defined as the maintenance over time of a previously trained response. In biofeedback

research, persistence might be assessed by having trainees return to the lab at a fixed time(s) after the termination of training, and asking that they produce the trained response without feedback. There is certainly an assumption made by biofeedback researchers and therapists that a trained response will likely persist over some period of time. The issue of response maintenance over time is, however, dealt with in conjunction with the related issue of transfer of control to settings other than the lab or clinic (generalization). Thus, Budzynski (1973) has required biofeedback clients to engage in home practice sessions either with portable biofeedback monitors or with non-instrumented relaxation techniques, such as progressive relaxation. Green, Green, and Walters (1970) have coined the phrase "Autogenic Feedback Training" to refer to their combination of biofeedback and Autogenic training (Schultz & Luthe, 1959). Besides enhancing the therapeutic efficacy of the biofeedback training, the combined training was said to assist the transfer of control. Other than having been recognized as a genuine issue in biofeedback training, the problem of transfer of control, both persistence and generalization of the response, has not been seriously investigated (DiCara, 1975).

Several biofeedback studies which have included some measure of persistence should be mentioned. First, the previous section concerned with the internal feedback loop

development is certainly relevant. Persistence of the response was, however, assessed immediately after training, rather than at some more distant time. Certainly the mechanism which might be said to account for persistence over time would be the internal feedback loop established during training. Staudenmayer, Kinsman, and Yaroush (1976) investigated the transfer of a trained EMG frontalis muscle response over one day, by alternating feedback and no-feedback sessions on consecutive days. They found that only subjects who could successfully discriminate EMG had significant transfer. Leibrecht, Lloyd, and Pounder (1973) reported that although EMG biofeedback was better than a non-instrumented technique for learning single motor unit control, both groups showed equal lack of transfer over a two week period. Such studies as these were not primarily designed to focus upon persistence, and hence provide only incidental evidence concerning the issue.

Persistence has been more thoroughly investigated in the general learning literature. A brief review of some of the findings will be helpful in generating ideas applicable to biofeedback. Skinner (1938) stated that increased resistance to extinction was provided by partial reinforcement when compared to continuous reinforcement. He further remarked (Skinner, 1950) that given proper experimental conditions, behavior would not need to extinguish at all when reinforcement is withdrawn. Evidence

that partial reinforcement leads to increased resistance to extinction was reviewed by Jenkens and Stanley (1950), and was demonstrated for human slot machine playing by Lewis and Duncan (1956). This increased resistance to extinction, or behavioral persistence, can be obtained by means other than partial reinforcement. Partial delay of reward (Donin, Surridge, & Amsel, 1967) or continuous delay of reward or downshift in its magnitude (Shanab & Ferrell, 1975) can all be effective in leading to increased response persistence.

Most of the persistence research involved non-humans, and it is likely that the results generalize to humans only under certain conditions. The human skills acquisition literature contains several relevant examples. Bilodeau and Bilodeau (1958) investigated the effects of delayed knowledge of response (KR) on acquisition, and found that the effect depends upon what subjects are required to do during the delay interval. Brackbill (1964) studied the effects of delayed KR on discrimination learning in children, and found that delayed reinforcement (and thus KR) led to improved performance. Brackbill and Kappy (1962) provided children with tokens zero, five, or ten seconds after correct responses to discrimination problems, and found that on a one-day retention test, children in the ten second group scored better than children in the five second group, who in turn did better than children in the immediate group. From this work and from the study (part of a series)

by Lewis and Duncan (1956), it appears reasonable to conclude that partial and delayed reinforcement or KR will, under certain conditions, lead to increased persistence of a behavior or retention of knowledge.

Amsel (1972) offered his general theory of persistence, based mostly upon resistance to extinction research in the animal learning literature. Based upon the principle of counterconditioning, his theory proposed that persistence develops whenever an organism learns to maintain an instrumental response under conditions which normally interfere with the learned response. Such interfering conditions might be the product of internal frustration responses due to delay of, downshift in the magnitude of, or partial reinforcement. Evidence has also been provided that persistence can transfer from one kind of aversive situation to another (Shanab & Ferrell, 1975). Thus, carrying this analysis into the biofeedback context (which is admittedly a long distance), it is conceivable that if reinforcement (the feedback stimulus containing KR) were delayed or arranged to be only partial, increased persistence over time might be obtained.

The problem of response maintenance has been of recent concern in the token economy literature. Kazdin and Polster (1973) have noted that token reinforcement programs generally are effective in maintaining behavior only while

they are still in operation, except where specific steps are taken to substitute naturally occurring conditioned reinforcers or to vary the parameters of reinforcement during acquisition. It has been found that both partial reinforcement (Kazdin & Polster, 1973) and delay of backup reinforcement at the token exchange (Jones & Kazdin, 1975) have been effective in increasing response maintenance after the withdrawal of the token program. This has been a different approach than that taken in biofeedback research, where clinicians and researchers have opted to augment the therapy program rather than experiment with the parameters of reinforcement to increase persistence.

Biofeedback may be somewhat different from other areas of performance, in that altered reinforcement contingencies might conflict with the postulated internal feedback, which would be immune from experimental influence. Thus, a feedback stimulus providing altered KR might be expected to conflict with the KR which an individual would receive from inside his body. In most cases the internal feedback is initially very weak, if present at all, and would likely not conflict with altered KR from external feedback. It is interesting to ask whether internal or external feedback would dominate, and for how long. In other areas of study this problem would be unlikely to arise, because external feedback would be the only source of KR or reward. Pitts and Posner (1967) have reviewed some perceptual-motor skills

acquisition literature, where intrinsic kinesthetic feedback competed with distorted external feedback. They noted that under such conditions, practice usually led to improvement, much as in learning an entirely new skill. It might, therefore, be reasonable to expect improvement with distorted feedback in biofeedback research.

The present research employs periods in which the feedback signal is delayed, embedded within standard biofeedback training sessions. It is expected that subjects receiving a combination of the delayed and immediate feedback conditions will display more alpha response persistence than subjects receiving just immeditat feedback. It is also expected that performance will progressively increase during the delayed feedback trials, as individuals learn to rely increasingly upon endofeedback references which differ from the distorted external feedback.

Method

Research Participants

Students were solicited from undergraduate psychology courses to volunteer as trainees in a "brainwave biofeedback experiment." They were told that they would have the opportunity to learn to control their brainwave patterns, and that their learning processes would be studied. All persons who reported interest were informed that they would receive a one-hour feedback session, and that if they displayed a certain pattern of activity, they would be asked to complete four additional sessions at scheduled times during a six-week period. Participants were unpaid, and received no course credit or extrinsic reward.

Twelve participants were required for inclusion in the various experimental conditions. Pilot research done by the author revealed considerable intersubject variability of training time required to produce consistently enhanced alpha during feedback sessions. In order to avoid a training-to-criterion approach and to reduce heterogeneity of alpha enhancement scores, it was decided that only volunteers who produced between 20% and 150% alpha enhancement, in baseline units, during at least two of the nine minutes of the first feedback (ACQ) trial would be accepted as trainees for the present research. The 20%

minimum figure was one suggested by pilot data; it appeared that persons demonstrating that much enhancement for two minutes would not simply be fluctuating around a baseline figure. It was hoped that any person producing this minimum would, therefore, continue to consistently enhance their alpha levels during the training sessions. The 150% maximum enhancement figure was expected to exclude subjects beginning with a very low baseline activity, for whom small changes in alpha strength from trial to trial would result in considerable variability in the alpha strength scores standardized by baseline. Such variability would not reflect meaningful psychological or behavioral activity. The selection criteria were designed, therefore, to maximize the likelihood that selected subjects would produce consistent alpha enhancement, and that small between-sessions variation in baseline alpha would not unduly affect the enhancement scores. Subjects were also screened for history of severe or regular headaches, epilepsy, head injury, and diagnostic EEG. One subject reporting epilepsy was excluded during this screening.

In order to secure the twelve required participants, eighteen vclunteers were screened as explained above. The six volunteers who did not satisfy the criteria of inclusion were given standard biofeedback training for the remainder of their hour sessions. They were then told that they did not show the pattern required in the present research, and

treated so as to minimize the possibility of perceived failure. One subject who was accepted as a research participant and who completed one session as such was disqualified due to extended illness which prevented scheduled participation.

Apparatus

The EEG was recorded using Beckman miniature silver/silver chloride skin electrodes attached to the right occipital and right frontal scalp areas (O2 and F4 in the International 10-20 system) referenced to the right mastoid. The electrodes were filled with Redux creme and held in place by an elastic band to maintain stable interface characteristics. Resistance in all cases was measured at less than 12K ohms just after electrode placement; spot checks of resistances at the end of some sessions showed no substantial change except for a possible slight decrease during sessions. Care was taken to insure that the resistances between each of the bipolar electrodes and the ground electrode were approximately equal.

The EEG signal was preamplified, amplified, filtered, and used to modulate the frequency of a continuous feedback tone by a Narco EEG Biofeedback System, which allows for artifact elimination and independent settings of threshhold and slope of the EEG-feedback relation. The artifact

elimination operated on the feedback signal by causing a discontinuity when the maximum threshhold was exceeded; the artifact inhibit setting did not influence the recorded alpha strength. The feedback parameters were adjusted individually for each subject and each session, allowing for a high information content to be maintained during the biofeedback training.

The input characteristics of the preamplifier include impedence of greater than 50 megohms and common mode rejection of greater than 120 dB at dc and 100 dB at 60 Hz. The filtering provides essentially flat response within the selectable passband of 8-13 Hz. The signal is attenuated by 46 dB within the first octave outside the passband and 30 dB per octave thereafter.

Filtered alpha was monitored from the Narco System and was quantified by a custom built resetting integrator. The monitored alpha was unaffected by settings of threshhold and feedback parameters, and was thus comparable over sessions even when these parameters were altered. The integrator was reset by a monostable pulse when its capacitor voltage exceeded a level set by an adjustable comparator. The reset pulses were recorded, along with filtered EEG analog signal and time in seconds, by a Grass Instruments Model 5D polygraph. The number of resets is linear with voltage in the alpha band, and is sensitive to both amplitude and

abundance characteristics of alpha.

The filtered alpha signal was time-average integrated (time constant of one second) and used to modulate the frequency of a feedback tone. This was accomplished by a Narco Audic Module NB-141, which provided a smoothly-changing feedback signal contingent upon alpha amplitude. The tone was displayed to the trainee by a Fisher speaker system, located six feet from and directly facing the seated trainee.

Procedure

Design Summary. Volunteers participated in four training and one follow-up session. All sessions were one hour, except for the fourth, which lasted two hours. Each of the twelve participants was randomly assigned to one of three experimental groups (NFB, TRA, & CON). All groups received three feedback training (ACQ) trials per session for three sessions. Groups were distinguished by tasks which were assigned to be done during probe intervals immediately following the ACQ trials. Feedback was not given for probe task performance, but data were recorded. One group, NFB, was instructed to practice the response that produced the feedback; a second group, TRA, was instructed to attend to and track the response that produced the feedback; and the third group, CON, was instructed to relax

by looking at scenic landscapes in a book. A slight departure from this design for the NFB group will be explained in a later section. Subjects in the three groups were run for three sessions, each session consisting of three ACQ and three probe trials. These three sessions completed the first part of the research study, making possible the analysis of performance during the probe tasks and a comparison across groups of ehnancement during feedback training.

After the third session, trainees were matched and assigned to either the persistence training group (PER) or the control group (PCON). The control group received considerable feedback training (ACQ) mixed with several intervals cf NFB trials. The PER group received identical training, except that about half of the ACQ training was replaced by feedback training in which the contingent feedback signal was delayed for nine seconds (DFB). This arrangement would allow for an evaluation of the effect of the combined ACQ and DFB training ("persistence training") versus the standard ACQ training. This evaluation was accomplished by examining the response persistence, that is, the ability to generate enhanced alpha without feedback present, in a session (Session 5) two weeks after the training.

Preliminary Procedures. Volunteers entered the

laboratory at appointed times and were seated across a table from the researcher. The screening questions mentioned previously were asked, and subjects were asked to read and sign a consent form. Subjects were then led to the experimental room, a 10 x 12 foot sound-attenuated, electrically-shielded chamber, and seated in an upright padded chair. All sessions were run in this chamber. The electrodes were attached, and an explanation of the operation of the electrodes and the biofeedback equipment was given. The only equipment present in the experimental room was the Narco preamplifier, a small signal generator, and the feedback speaker. Two tables and a clinical couch were also present in the otherwise bare room. The subject sat facing a half-silvered glass window, through which gross physical movement could be visually monitored from the adjacent equipment room. A ceiling-mounted recessed fixture, located directly over the subject chair, provided a constant dim level of lighting, which measured a maximum of 1.8 foot-candles of illuminance from head level directly under the light and a minimum of 0.2 foot-candles from other head-level locations in the chamber.

After the basic operation of the biofeedback equipment was explained, the researcher gave the feedback and then the probe task instructions. These were followed by baseline instructions, in which the subjects were told to "rest, be still, and do not do anything related to any other tasks of

this experiment. Keep your eyes open." (These baseline instructions were repeated again at the end of each session, via intercom, for a second baseline recording at that time.)

After giving the baseline instructions, the experimenter retired to the equipment room for the remainder of the session, until it was time to disconnect the subject. Further communication during the sessions was by intercom. On two occasions it was necessary to reenter the experimental room in order to examine electrode connections.

Feedback Instructions. After the electrodes were placed, verbal instructions for the feedback training were given. Participants were told (1) that the feedback tone varied in pitch as their brainwave pattern varied, (2) that their task was to "do what you will to raise the pitch of the tone, and keep it raised as much of the time as you are able", (3) to avoid using physical movement, especially of the face or eyes, as a method of controlling the tone, (4) to keep the eyes open during all sessions, and (5) that they could ask important questions at any time via the open intercom. It was also suggested that persons who successfully control the tone often report that they begin by not trying too hard, but instead begin by (1) observing the variability of the tone, (2) attending to experience and feeling during the high-pitched tone, and (3) controlling feelings and experience to control the tone. A small signal

generator, set at 10 Hz, was then connected to the preamplifier and varied manually between 0 and 80 microvolts in order to demonstrate the variability of the tone. Instructions given to subjects in sessions other than the first verbally reinforced these more extensive instructions given during Session 1. The feedback instructions were given to all subjects, and apply to the ACQ and DFB tasks. Subjects also received instructions appropriate to the assigned probe task; these instructions are given below.

NFB Probe. Subjects assigned to NFB group were told: "During some parts of your training, there will be no tone. Use this time to practice what you have learned; do what you would to raise the pitch of the tone, as though it were present. Keep your eyes open."

The first probe trial of Session 1 for NFB trainees, instead of being an NFB probe, was a delayed feedback (DFB) trial. This was a departure from the procedure mentioned in the Design Summary, allowing for a test of the subjects' use of the informational content of the feedback signal. The NFB group trainees, therefore, received eight NFB probe trials preceeded by one DFB probe trial.

DFB Probe. As DFB probe trials were a continuation of ACQ trials, with feedback present in both trial types, there were no separate instructions for DFB. The delayed feedback was produced by routing the feedback signal through two

consecutive tape recorders on-line. The tape ran from the feed reel on recorder 1, through the tape heads of recorder 1, then through the tape heads of recorder 2, and finally to the take-up reel of recorder 2. The feedback signal was monitored from the speaker output of the Narco unit and fed to the auxiliary input ot recorder 1, which was in record mode of operation, and was reproduced by recorder 2 in playback mode. The delayed signal was monitored from the speaker output of recorder 2, and used to activate the speaker in the experimental room. It was possible to achieve a wide range of delay times by varying tape speed and the distance between the recorders. A nine second delay period was used throughout the present research.

TRA Probe. In the tracking task, the trainee held a response button in each hand. The pressing of a button closed a circuit which included either a red or a green light, visible to the experimenter. The onset of a light was used as a signal for the operation of an event marker on the polygraph record. The TRA subjects were instructed: "During some parts of your training, there will be no tone. You are to use these two response buttons (one hung over each arm of the chair). Hold this one in your right hand, and the other one in your left hand. If you believe that the tone, were it present, would be higher than average in pitch, press and hold the button in your right (left for half the subjects) hand. If you believe that the tone, were

it present, would be lower than average in pitch, press and hold the button in your left (right) hand. You will always be pressing one button or the other, but not both at once. Keep your eyes open. Do you understand?" The trainees' responses were recorded alongside the records of integrated alpha strength and filtered analog EEG, which allowed for a comparison of alpha strength under the two tracking responses.

CON Probe. Trainees in this group were instructed: "During some parts of your training, there will be no tone. During those times, you are to browse through the book laying on the table to your left (a Sierra Club book of attractive landscapes). You are to rest, so don't do anything related to the other tasks of the experiment. Keep your eyes open."

PER and PCON Training. The training received under these conditions was composed of feedback trials and embedded NFB practice trials. PCON training consisted of alternating ACQ and NFB trials, while PER training was identical except that about half the ACQ trials were replaced by DFB trials.

Having explained the training and instructions received for the different trial types in this research, it is time to consider the arrangement of training and probe trials to compose the sessions. Data recording in each session began

with a three-minute ("minute" refers to a fifty-second period throughout this research in order to facilitate data tabulation) baseline recording trial. The first training trial, lasting nine minutes, followed baseline, and was used as the screening trial during the first session. The ACQ trial was fcllowed by the first probe trial, and then immediately by the second ACQ. Each of the first three sessions contained three ACQ and three probe trials, plus initial and final baseline. During Session 1, the first two ACQ trials were nine minutes, the first two probe trials were five minutes, the third ACQ trial was five minutes, and the third probe was three minutes. The second and third sessions contained three nine-minute ACQ trials, each followed by a three-minute probe trial.

There was a total of nine ACQ trials for each subject. There were nine TRA and CON probe trials, and eight NFB probe trials. The latter is due to the replacement of one NFB trial by a DFB trial, as described above. The ordering of tasks within the first three sessions is displayed in Table 1. Trainees in all groups received the same amount of ACQ trials, the only difference being the types of probe trials assigned.

Following the third session, subjects within the three groups were matched on the basis of their ACQ performance during Session 3, and then assigned to groups PER and PCON

SESSION		
1	TASK*	B A P A P A P B
	TIME	3 9 5 9 5 5 3 3
2,3	TASK*	B A P A P A P B
	TIME	3 9 3 9 3 9 3 3
4 (PER) B	TASK*	B N; A D A D N A D N A D N A
	TIME	3 9 5 5 5 5 5 5 5 5 5 5 5 3
4 (PCON)	TASK*	B N; A N A N A N A B
	TIME	3 9 20 5 10 5 10 5 5 3
5	TASK*	B N B
	TIME	3 9 3

*TASKS
B - Baseline trial
A - ACQ trial
P - Probe trial
N - NFB trial during Sessions 4 & 5
D - DFB trial during Sessions 4 & 5

Table 1. Arrangement of trials within sessions. The trial length, in minutes (50-second periods), is given directly beneath each corresponding task.

for the remainder of the experiment. As six of the participants began Session 1 during the same week, and the other six at a later time, there were initially two subjects from each of the three original groups. These pairs were split, with one going to PER and the other to PCON. When the final group of six subjects finished Session 3, they were split in the opposite way; the subject with the greater alpha enhancement level during Session 3 ACQ was assigned to the same group as the subject from the first pair with the smaller alpha enhancement level. Groups PER and PCON, then, each contained two trainees from each of the three initial groups, roughly matched on the basis of previous alpha enhancement.

Two weeks after the completion of the third session, the trainees reported to the lab for the fourth session. Session 4 began with a baseline recording, followed immediately by a nine minute NFB probe task, in order to determine the amount of alpha persistence, without feedback but with instructions to respond, over the two week period. Both groups (PER and PCON) received additional training with contingent immediate feedback (ACQ), but for PER group subjects, the second half of each ACQ trial was replaced by DFB trials without warning or differentially instructing subjects. Both groups also received NFB trials alternating with the others, so that they might gain practice with the criterion measure of persistence. The ordering of tasks

within Session 4 is contained in Table 1.

Two weeks after completing Session 4, trainees reported to the lab for Session 5. The purpose of this session was to evaluate the persistence of alpha due to the training of Session 4, and consisted of a nine-minute NFB trial preceeded and followed by baseline recording.

Results

Percent Baseline Scores

All alpha strength scores, measured by the number of integrator reset pulses, were standardized by dividing them by the average baseline score for the same session. There were two three-minute baseline trials in each session, one at the start and another at the end of the session. It had been observed during pilot research that baseline alpha, measured every ten minutes, had been quite stable within sessions. Thus, in the present research, the two baseline trials per session should be representative of baseline activity during the session. Baseline alpha, averaged over subjects for the first three sessions, was calculated and found to vary by less than five percent. This is a markedly different pattern from the rising baseline observed during eyes-closed alpha enhancement training.

For each subject in each session, the average alpha strength for the two baseline trials was computed. Then the alpha strength score for each feedback and probe trial was divided by the mean baseline score, yielding an alpha strength score in percent baseline units. A score of 100 would always mean that the alpha strength was equal to baseline activity; a score of 150 would mean that the alpha strength was one and one-half times that of baseline, and so

on. Scores below 100 indicate alpha strength less than baseline level.

Delayed Feedback Control

The effect of immediate informational content of the feedback on alpha strength was examined in a subjects x trials design with four subjects and eight trials. The first two ACQ trials for NFB group, with the intervening DFB probe trial, were blocked into three-minute segments, so that there were three three-minute trials in each ACQ period. Since DFB was five minutes in length, the third minute was included twice, as the last minute of the first three-minute segment and as the first minute of the second three-minute segment. Thus, there were three ACQ trials followed by two DFB trials followed by three ACQ trials, for a total of eight trials.

The results of the analysis indicate a significant trials main effect ($F(7,21) = 9.59$, $p<.01$, $MSe = 191.43$). More important, however, are the cubic and linear trends, which were calculated using orthogonal polynomials applied to trials cell means. A significant cubic trend ($F(1,21) = 9.20$, $p<.01$) verifies the statistical significance of the behavioral reversal effect evident in Figure 1. Trainees showed enhancement above baseline (100) during the three segments of the first ACQ trial, then performed at

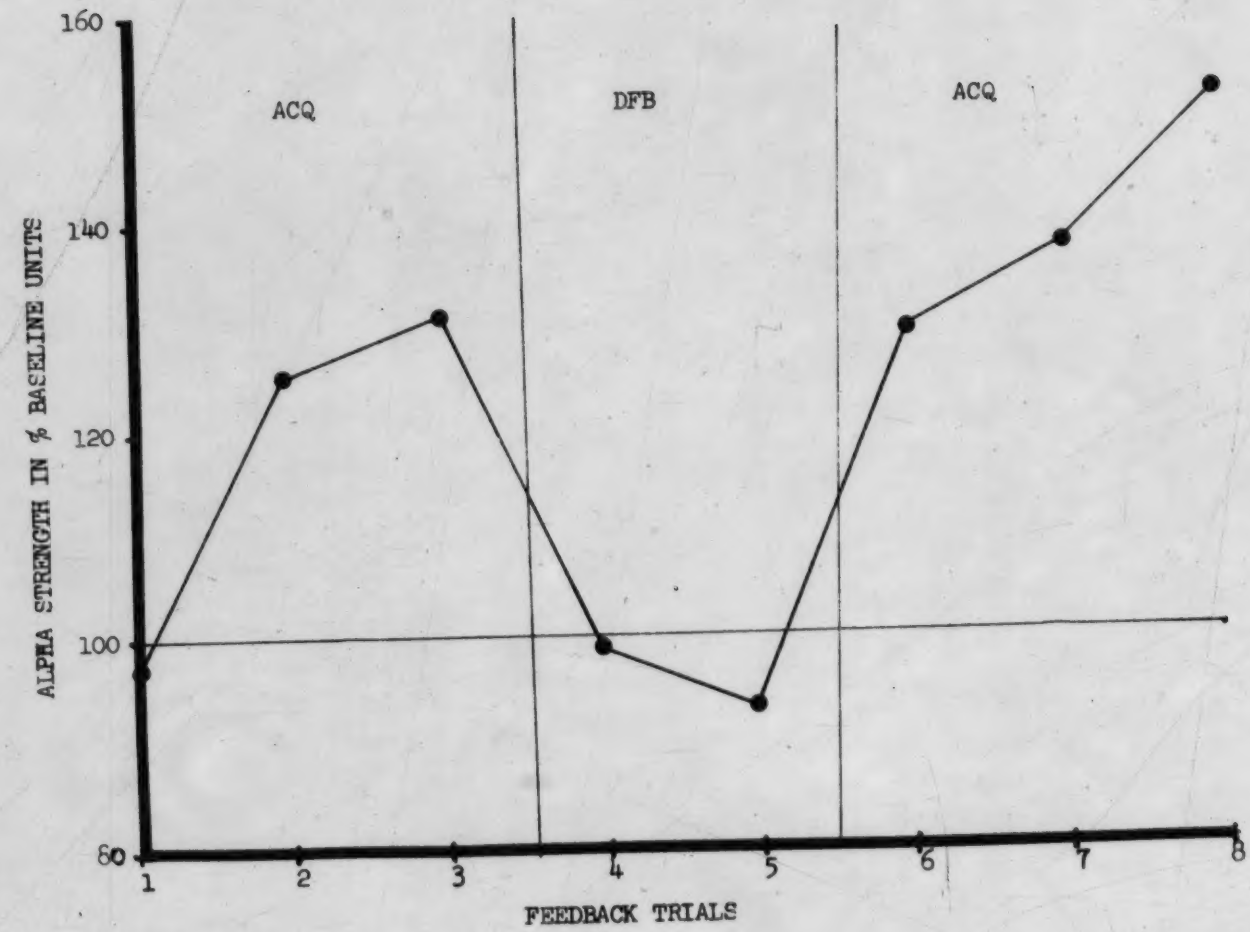

Figure 1. Alpha strength during the first two ACQ trials and intervening DFB probe trial for NFB group during Session 1.

approximately baseline level during the delayed feedback probe. Data from the second ACQ period reveal that the reinstatement of immediate feedback led to the recovery and further enhancement of alpha strength. A significant linear trend ($F(1,21) = 22.31$, $p<.01$) indicates that there was an overall increase in performance over trials, indicative of learning. This latter statement can be made more positively than in most previous research, in that the reversal during DFB rules out spurious effects in accounting for the performance increase.

Since an operant reversal (A - B - A) design is often applied to individual subjects, the data from the NFB trainees is presented in Figure 2. It can be seen that all subjects followed the reversal and recovery pattern demonstrated in the group data.

Alpha Discrimination

The ability to discriminate high from low alpha content in the EEG was tested by examining the linear trend of performance of the TRA group on their tracking task. First, the data were transformed to a discrimination score for each probe trial for each of the four subjects. This was accomplished by first totalling the accumulated alpha strengths for the high tone and low tone button presses separately, and dividing each by the total number of seconds

for the respective button presses. This operation provided the average alpha strengths for both button presses. Next, the mean alpha strength for the low tone was subtracted from the mean alpha strength for the high tone, yielding the discrimination score. Such a score was calculated for each three-minute TRA probe trial for all subjects.

The discrimination scores were subjected to a subjects x trials analysis of variance, with four subjects and nine trials. The results of the analysis indicate that trainees learned to discriminate high from low alpha strength in their ongoing EEGs. An examination of Figure 3 reveals that the tracking began in Session 1 at approximately chance level, and improved somewhat over the course of training. The significant linear trend ($F(1,24) = 7.66$, $p<.02$, $MSe = .0026$) is more interesting than the simple fact that subjects discriminated in the right direction, in that it indicates that discrimination ability is acquired during the training sessions. This finding rules out the possibility that subjects make the relevant discrimination immediately, but then take time to learn to produce alpha in increasing quantities.

Though the method of computing discrimination scores controlled for performance based solely upon raising or lowering the amount of alpha during the tracking task, it is still possible that during more successful tracking

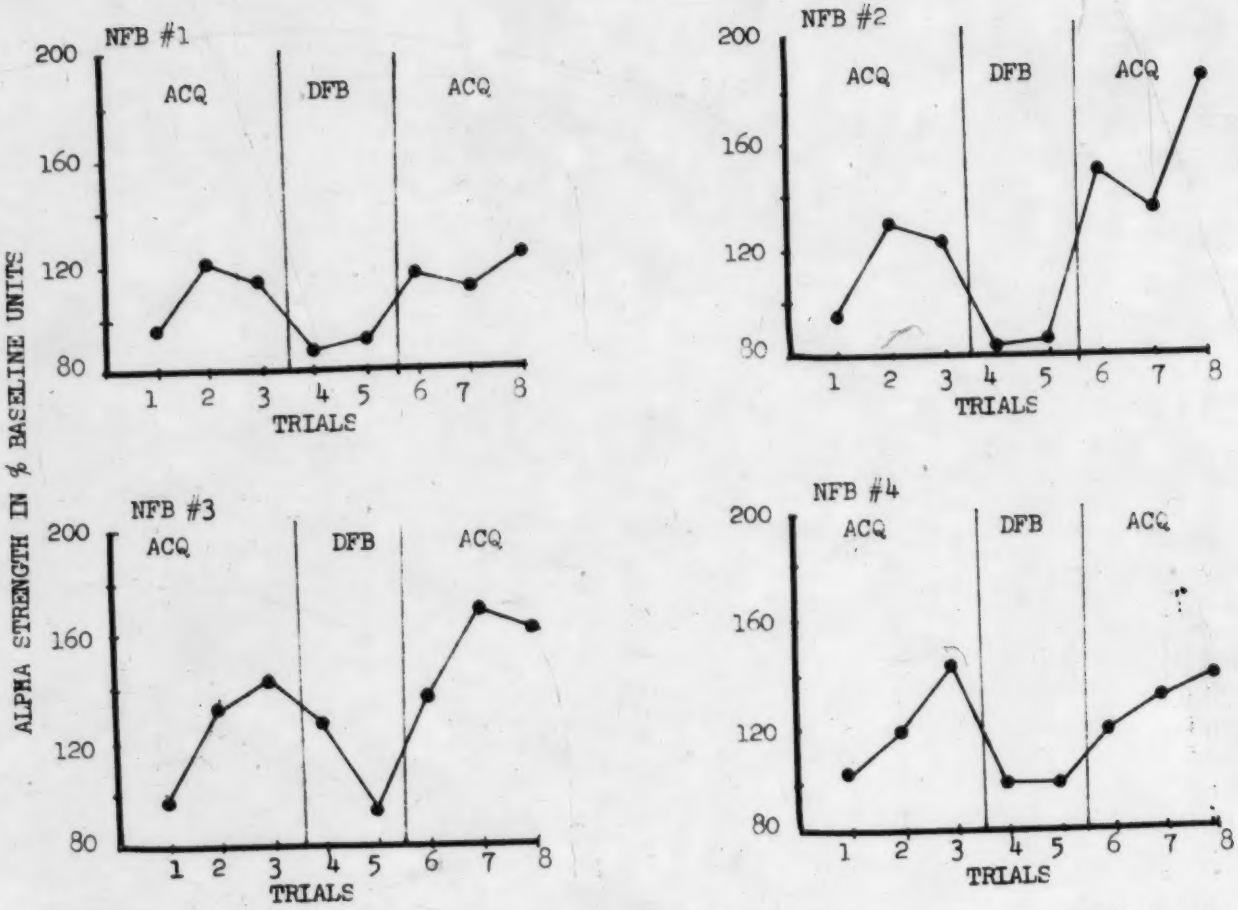

Figure 2. Alpha strength during Session 1 ACQ/DFB/ACQ trials sequence for individual subjects in NFB group.

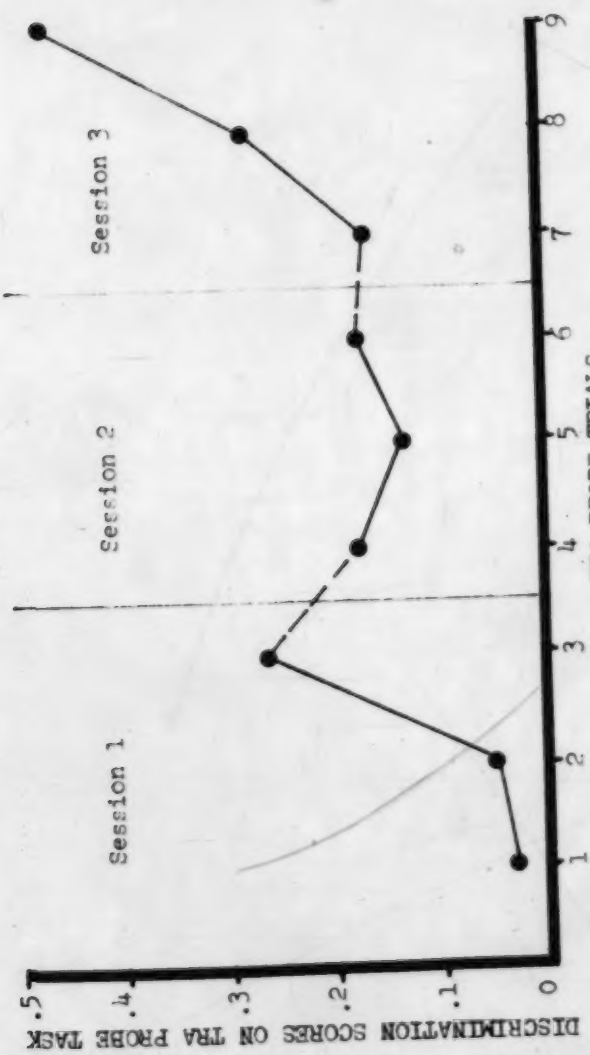

Figure 3. Discrimination ability; TRA task performance as a function of trials.

sessions, subjects produced an overall elevated or depressed alpha level. This possibility was examined by computing the Pearson product-moment correlation between discrimination scores and alpha strengths for all 36 tracking trials (nine trials for each of four subjects). The correlation coefficient of +.32 fails to achieve significance at the .05 level ($t(34) = 1.97$, $.05<p<.1$), but might be considered as marginally indicative of positive relationship between tracking performance and alpha strength during the tracking. The scattergram of TRA performance and alpha strength is presented in Figure 4.

Endofeedback Loop Development

Performance on the NFB probe task was interpreted as an indicator of the development of an internal feedback loop. This performance was examined in a subjects x trials design with four subjects and eight three-minute trials. The final two minutes of the five-minute probe trials of Session 1 were dropped for the analysis; they had been given simply to allow for more practice on the probe tasks. There was a significant trials main effect ($F(7,21) = 3.97$, $p<.01$, $MSe = 1151.31$), and more importantly, a significant linear trend over trials ($F(1,21) = 17.66$, $p<.01$). CON group showed no such increase in performance during their probe tasks, ruling out a possible carry-over effect interpretation of the NFB performance. The NFB data are presented in

Figure 4. Scatterplot of the relation between tracking (TRA) performance scores and alpha strength scores during the TRA trials.

Figure 5.

Effect of Probe Task on Enhancement

The effect of what subjects did between feedback training trials on alpha enhancement during the feedback (ACQ) trials was examined in a groups x sessions x trials analysis of variance, with subjects within groups. There was a significant main effect for groups ($F(2,81) = 5.26$, $p<.01$, $MSe = 1346.1$), using a pooled within-groups error term. Group means were 170.24, 153.96, and 142.33 for NFB, TRA, and CON groups respectively. Individual comparisons employing orthogonal polynomial coefficients reveal a significant difference for NFB versus the other two groups ($t = 2.96$, $p<.01$, $SD = 7.48$), which did not differ significantly from each other ($t = 1.35$, $p>.1$, $SD = 8.65$).

A significant groups x trials interaction ($F(4,18) = 4.83$, $p<.01$, $MSe = 357.68$) is pictured in Figure 6, which shows that the NFB group had a higher rate of enhancement over trials than the other groups. Thus, NFB subjects produced the most alpha during training, and this effect was due to a more rapid rate of enhancement over trials.

Other results of the analysis include an obvious significant trials main effect ($F(2,18) = 55.27$, $p<.01$, $MSe = 357.68$), a significant sessions main effect ($F(2,18) = 5.20$, $p<.02$, $MSe = 2320.41$), and a significant sessions x

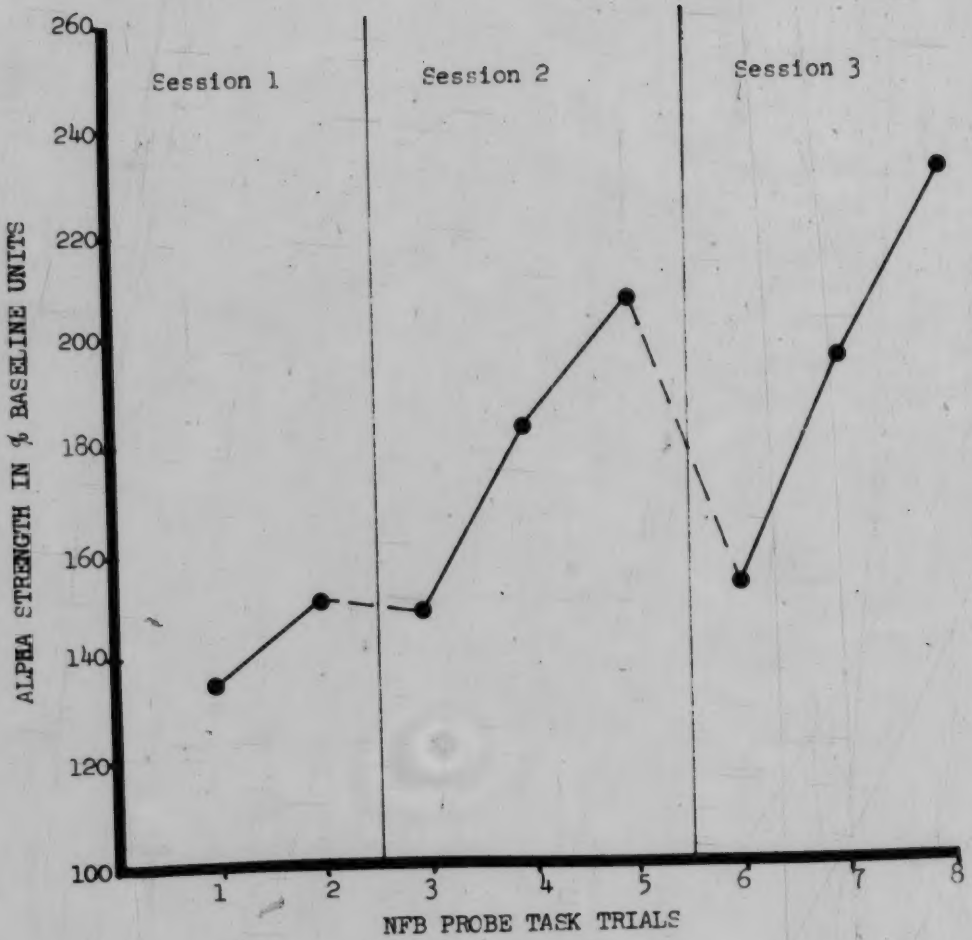

Figure 5. Endofeedback loop development; alpha strength as a function of NFB probe task trials.

trials interaction ($F(4,36) = 3.71$, $p<.02$, $MSe = 363.49$). The session means were 134.37, 165.67, and 166.49 for the three sessions in order. The sessions x trials interaction, which can be examined in Figure 7, reveals that Sessions 2 and 3 had nearly identical alpha performance for all three trials. Alpha strength increased more rapidly over trials during Sessions 2 and 3 than during Session 1.

Delayed Feedback Performance During PER Group Training

The performance of PER group trainees during the Session 4 delayed feedback task was examined in a subjects x trials design with six subjects and four trials. It had been hypothesized that the persistence training would operate by weakening the dependence of alpha enhancement performance upon the external feedback signal. If this were the case, then as trainees were to rely decreasingly upon the external feedback (and, perhaps, progressively more upon endofeedback mechanisms), performance during the DFB trials should improve.

The data are displayed in Figure 8, which depicts an apparently linear increasing relation of alpha strength over DFB trials. There was a significant trials main effect ($F(3,15) = 17.74$, $p<.01$, $MSe = 195.44$) and a significant linear trend ($F(1,15) = 53.00$, $p<.01$).

The enhancement data during the last two ACQ trials of

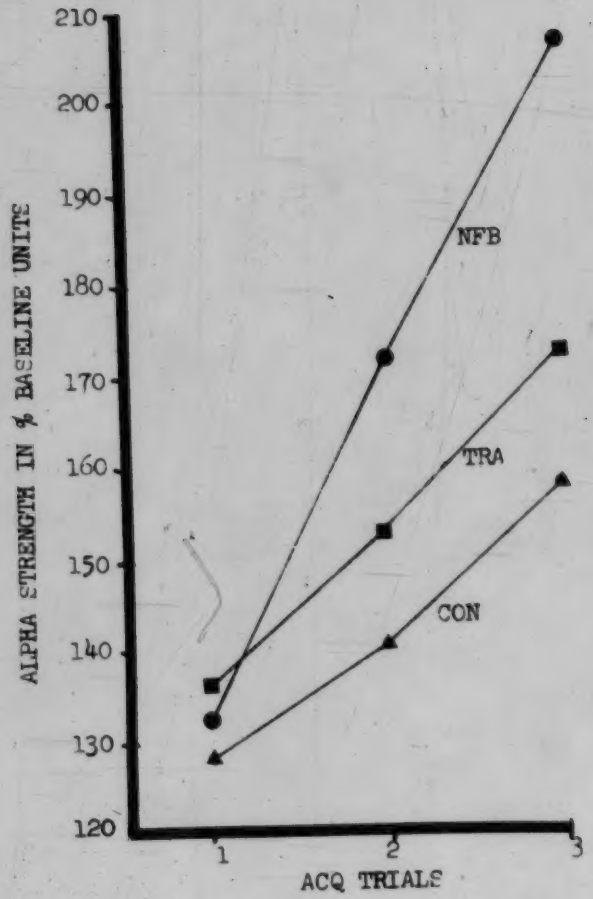

Figure 6. Alpha strength over trials, collapsed across Sessions 1, 2, and 3, for the three probe groups.

Figure 7. Alpha strength during ACQ training trials for the first three sessions.

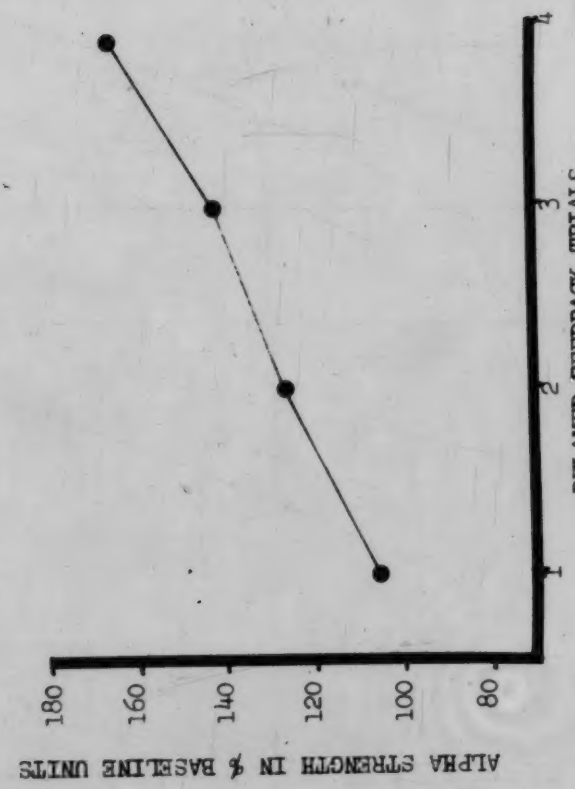

Figure 8. Alpha strength during DFB trials for PER group Session 4 training.

Session 4 for PER and PCON were also examined. Since the ACQ trials for the PCON group were ten minutes in length rather than five, only the first five minutes of the trials were included. A t-test on the means of the twelve total trials per group indicated that the enhancement data do not support a conclusion that the two groups showed different levels of acquisition ($t(22) = 0.813$, $p>.4$, $SD = 21.23$). In fact, the PCON group showed more enhancement than the PER group (means of 205.14 and 187.87).

Persistence Training

In order to evaluate the effect of the persistence training a groups (PER and PCON) x initial groups (NFB, TRA, and CON) x trials analysis was carried out. The data analyzed were persistence gains due to Session 4 training. At the conclusion of Session 3, subjects had been matched on enhancement during Session 3 ACQ;, the effects of assigning these matched trainees to the two groups was evident in the NFB persistence trial at the beginning of Session 4. The mean persistence for the PER group was 126.05, and for the PCON group was 131.10. Using the persistence gains, a measure derived from percent baseline scores by subtracting the persistence level at the beginning of Session 4 from that of Session 5, was an additional control against possible experimenter bias.

The persistence performance for the two groups across trials is displayed in Figure 9, which also includes the Session 4 persistence test. There was a significant groups main effect ($F(1,6) = 32.97$, $p<.01$, $MSe = 860.73$), demonstrating that PER subjects, who received the DFB as part of their training in Session 4, produced higher alpha strength levels in Session 5 than did PCON subjects. The mean persistence gain for PER was 45.74 baseline units and for PCON was -0.41 units. Total persistence during Session 5, which consists of the gain added to the Session 4 pre-training persistence levels, was 171.79 and 130.69 percent baseline units for PER and PCON respectively.

In order to discover whether or not the persistence group main effect was consistently obtained across the three initial groups, the groups x initial groups interaction was computed and found to be significant ($F(2,18) = 6.38$, $p<.05$, $MSe = 412.28$). Figure 10 shows the interaction. Although strongest for the CON group, it can be seen that PER subjects demonstrated more persistence than PCON for all the initial groups, underscoring the strength of the persistence training main effect. The error term used in testing the interaction consisted of two within-subjects error term components pooled to increase degrees of freedom.

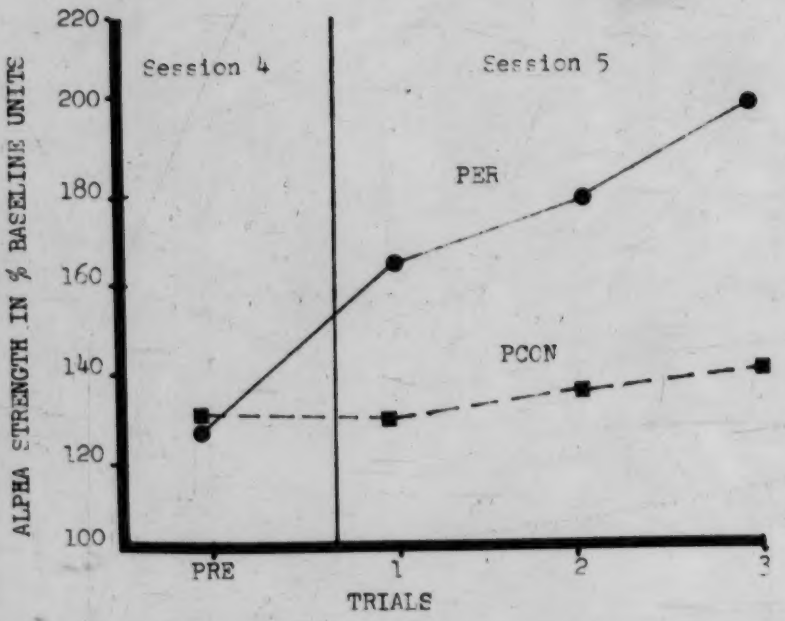

Figure 9. Persistence of PER and PCON training groups during NFB trials in Session 4 (pre-training) and Session 5 (post-training).

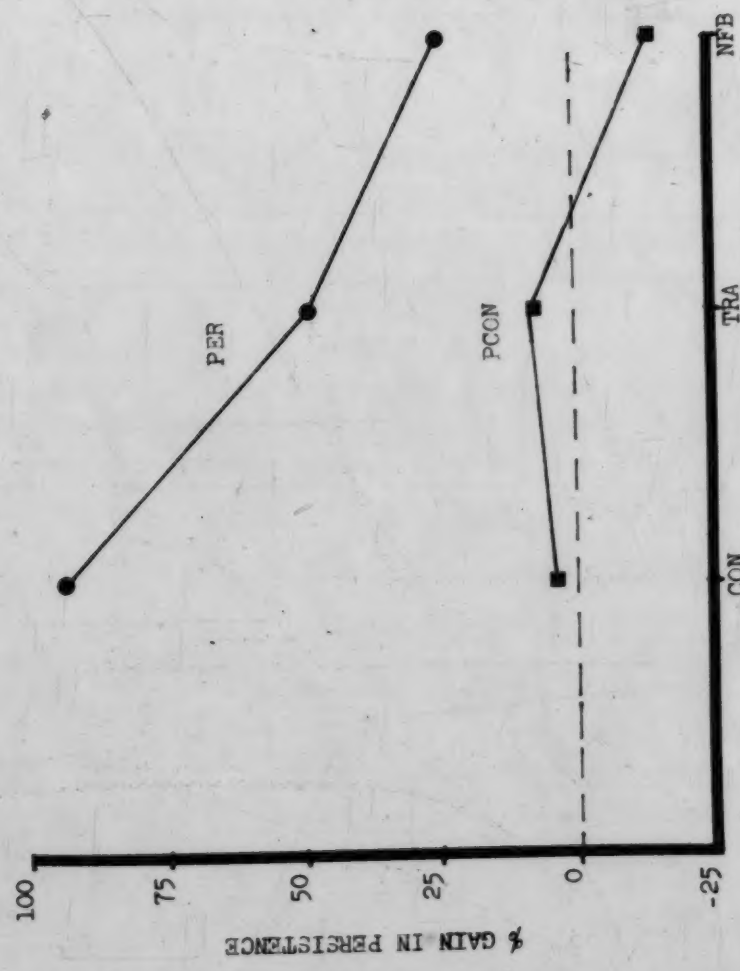

Figure 10. Percent gain in persistence from Session 4 to Session 5 for initial (Probe) group x final (Persistence) group interaction.

Discussion

Alpha Enhancement

One of the most potent criticisms of the alpha enhancement research, especially relevant to eyes-open alpha, is that observed alpha increases in the presence of feedback are not a result of learning, but instead a recovery to natural alpha levels through disinhibition of factors that block alpha (Lynch and Paskewitz, 1971). This may be manifest as a rising baseline (Kamiya, 1969; Hart, 1968) or as similar alpha increases in subjects receiving contingent and noncontingent feedback (Lynch, et al., 1974; Cleeland, et al., 1971). The delayed feedback probe given to NFB group trainees controlled for this as well as other sources of influence on enhancement, leaving just the informational content of the feedback stimulus to account for the difference between the ACQ and DFB trials.

In the present study, the disinhibition hypothesis would predict that disinhibition would begin in the first ACQ trial, and continue through the DFB, since performance should not depend upon informational relevance of the feedback. Hardt and Kamiya (1976b) argued that disinhibition was very likely in Plotkin's (1976a) research due to potentiation by the eyes-open and lights-on conditions. Since the present research used experimental

conditions similar to Plotkin's, and since alpha strength decreased to approximately baseline level during the DFB probe, the disinhibition hypothesis did not receive support. Supported by this research is the hypothesis that alpha increases during biofeedback training under the present experimental conditions are due to learning. The fact that all subjects showed the same pattern of alpha strength in this portion of the research demonstrates that the learning hypothesis in tenable across subjects.

The motivational and instructional effects as well as the experimenter-subject interactions which can all plague between-subjects designs are also eliminated in within-subjects control procedures. There were no differential instructions for the ACQ and DFB periods, thus eliminating any kind of biasing of the results. Additionally, the single subject control does not have the disadvantage of a yoked subjects control. Church (1964) has pointed out that when subjects of different reactivities are paired in a yoked design, there is a built-in bias in favor of the experimental group, whose reactivity determines reinforcement level. Also eliminated by the DFB control procedure is the potential evocative effect of the feedback stimulus (Selzer and Pehmi, 1975) or other environmental factors. Subjects receive feedback during the entire procedure, and there is no reason to expect that delayed and immediate feedback would entail different evocative effects.

It would be interesting to compare the effects of delayed with noncontingent feedback. Delayed feedback is a slightly better control procedure in the present research, since overall amount of feedback is still contingent on the subject's alpha activity, preserving the information concerning how well a subject does over a period of time. That is, the immediate information is separated from the cumulative information which is similar to that provided by a digital score at fixed intervals throughout training. Over a trial, a subject could still form an impression of how much alpha he produced from the delayed feedback. This is not the case with noncontingent feedback. Both delayed and noncontingent feedback are like partial reinforcement, in that sometimes the alpha activity and feedback will coincide. When they do not, however, the subject receives misinformation. Only with delayed feedback, however, does the level of immediate correspondence between the feedback and alpha activity depend upon actual amount of alpha produced, its variability, the transfer function between the alpha strength and the feedback tone, and the psychophysical function relating the tone and subjective impression of the tone.

The delayed feedback control technique could become very useful in both experimental and clinical biofeedback training programs. The DFB probe can be inserted at any

time in on-line fashion in order to assess the effect of the feedback separate from all other factors. This technique does not interfere with the training regime, and can be meaningfully interpreted for individuals. Often in the clinic, an active placebo environment is maintained, so that all factors which might contribute to therapeutic effect are included. Such environmental and interpersonal support may contribute to the overall level of physiological control. The delayed feedback technique could be used to separate the effect of factors such as these from that of feedback information use.

Alpha Discrimination

The discrimination score subjected to analysis was the difference between average alpha strengths for the "high tone" and "low tone" button presses. As a separate score was computed for each trial, subjects could not manipulate their scores by employing a strategy of overall increase or decrease of alpha strength within trials. In order to achieve a positive score within any trial, a subject must show actual discrimination within that trial. While there is no actual evidence that subjects were discriminating alpha itself rather than a correlate or mediator of alpha, such a distinction could not likely be made with current experimental techniques.

It is reasonable that subjects could increase their probabilities of success at the tracking task by increasing the variabilities of their alpha strengths during the TRA probes. Hardt (1975a) speculated that this explanation might have accounted for Legewie's (1975) failure to replicate Kamiya's (1962) discrimination results. If subjects in the present study increased their EEG variabilities, it is almost certain that most of the increased variability would have been produced by raising overall alpha strengths during the TRA trials. This is due to the eyes-open experimental condition, which allows for easier increase than decrease in alpha, plus the nature of the training given. Subjects did not receive any alpha suppression trials, and would likely keep within the limits of the training to increase variability. Increased alpha strength on any trial, then, would lead to an easier discrimination problem on that trial. A significant positive correlation between alpha strength and discrimination scores on the same TRA trials would support the notion that subjects used increased alpha strength variability to assist in the discrimination task. The mild correlation of +.32 just failed to achieve significance at the .05 level, providing marginal support for the hypothesis. While it must remain equivocal as to whether subjects succeeded at discriminating high from low alpha strengths by increasing variability, this method would in

itself not provide an explanation of successful discrimination; subjects would still need to discriminate between high and low alpha in the now-more-variable EEG.

The fact that alpha discrimination was learned during the alpha self-regulation training supports the view that discrimination is part of the learning activity. The current research provided subjects with no feedback for their tracking performance, which served only as a test of their abilities. The fact that the first two trials (Figure 3) were at approximately chance level supports the notion that alpha discrimination was progressively acquired during the biofeedback training. The significant linear trend contrasts with Legewie's (1975) result of no increased performance over trials.

The heart rate discrimination research shows that discrimination ability is related to HR control with feedback (McFarland, 1975; Brener, 1974b; Clemens and MacDonald, 1975) and transfer of control to no-feedback trials (Clemens, 1976). It is interesting to speculate about whether direct alpha discrimination training via a tracking task with feedback would lead to better alpha enhancement or transfer of control. It seems likely that such would be the case; besides the heart rate studies, there is evidence that successful discrimination of EMG frontalis activity predicts transfer of control

(Staudenmayer, et. al., 1976). For alpha, the feedback from the tracking task might be the frequency of a tone modulated by the difference in alpha strength between cortical activity and that represented by the subject's response on a continuously-variable lever. There is probably no reason for a two dimensional display (frequency and amplitude), as results from this study and others indicate that alpha strength is a measure with which trainees can work successfully. It is probably also important that a tracking task be used, as the discrete trials approach requires both orientation toward the signal-to-respond and memory.

The results from the discrimination test, when considered together with the results from the DFB and NFB probes, very strongly support an interpretation that the eyes-open alpha enhancement is due to learning. The subject is using the informational content of the feedback stimulus, able to discriminate at least two levels of the activity, and able to produce it in the absence of external feedback.

Endofeedback Loop

The significant performance increase during the NFB probe trials suggests that subjects learned to produce enhanced levels of alpha by manipulating an internal variable or state. The gradual increase in alpha during NFB

within sessions, and the pattern of decrements between the last trial of one session and the first trial of the next, is consistent with what would be expected for the development of a new behavior.

Peper (1970) originally used the phrase "internal feedback loop" to explain how subjects could alter their alpha performance by differentially attending to visual stimuli. Endofeedback loop is used here in a broader sense. It implies the establishment of an internal reference signal, which can be compared with ongoing EEGs to generate an error signal, which then modifies the ongoing EEG activity (negative feedback to the input of a comparator). Viewed in this way, an endofeedback loop can account for the self-regulation of alpha in the absence of feedback.

Alpha Persistence and Delayed Feedback Performance.

The results of the persistence training were dramatic. The control group (PCON) did not gain in persistence due to Session 4 training, while the experimental group gained extensively. The control group was an active one, in the sense that while PER received the DFB training, PCON received additional ACQ trials, which were expected to be beneficial.

The first DFB trial of the persistence training had the same effect as the DFB probe inserted after the first ACQ

trial of Session 1; it led to a depression of performance to approximately baseline level. Performance on subsequent DFB trials, however, progressively increased. This increase was hypothesized to be predictive of increased alpha persistence in the future. Persistence is really the indepencence of the behavior from immediately present or very recent external feedback; it is a reliance upon internal cues. During the DFB trials, the subjects have two sources of feedback, one of them external and the other internal. Their training had been to rely upon the external feedback, but it was demonstrated here and by Travis, et al. (1974a) that an endofeedback reference was being strengthened by the feedback training. The external feedback during DFB is contingent upon the subject's alpha, but not substantially useful as an information source capable of leading to learned self-regulation. It does offer a conflict, however, between internal and external sources of information. The successful resolution of the conflict is a shift in dependence (or stimulus control) from the external to the internal source of feedback. This shift leaves the trainee more independent of the external feedback, and manifests as persistence. It is reasonable to hypothesize that the persistence training procedure would also lead to better generalization of the trained response to stressful environments, where successful self-regulation means attending to appropriate internal cues in the face of

external and internal noise.

An additional point of importance is that it seems insufficient to establish an internal feedback loop in order to learn persistence. Both groups showed about equal performance on the NFB task of Session 4. As well, the persistence gain was independent of the alpha strength produced during ACQ trials, with PCCN showing slightly greater enhancement in Session 4. Thus, eventual persistence was predicted only by the DFB trials and performance, and not by any other aspects of performance during Session 4. It is likely, then, that performance during a DFB trial or sequence would be the best predictor of subsequent persistence. Work is planned which would allow the experimenter to make quantitative predictions of both informational use of the feedback stimulus and persistence of the response.

Two alternative explanations for the persistence results should be considered. First, it is possible that the DFB trials given to the PER group in Session 4 allowed for a different kind of feedback reinforcement of alpha activity. It has been previously mentioned that delayed feedback will, at any point in time, vary in accuracy (immediate relevance) depending upon the variability and amount of alpha and the psychophysical function relating alpha to the feedback tone. This variable accuracy in the

feedback could operate differentially to provide relatively more reinforcement for long trains of high alpha activity. For example, when high alpha content is maintained for the full delay interval, the delayed feedback would be relevant to the current alpha activity. In order to decide between this possibility and the endofeedback alternative in accounting for the persistence results, DFB training of Session 4 could be compared to random, non-contingent feedback. The endofeedback hypothesis would predict similar results for the two conditions (DFB versus non-contingent feedback probe trials), while the differential reinforcement hypothesis would predict that the subjects receiving DFB would show more persistence due to the reinforcement value of DFB.

A second possible explanation for the persistence results is that the PCON group, which received more ACQ trials than the PER group, was subjected to overlearning. Overlearning can have the effect of leading to faster extinction of a learned response, particularly in discrimination reversal problems. In the present research, the overlearning explanation would suggest that the persistence of the PCON group was suppressed relative to the PER group, leading to the obtained results. Overlearning, however, also leads to increased retention over time of a learned response, and the persistence test employed in the present research bears closer resemblance to a retention

test than to extinction trials. While the overlearning hypothesis could be tested by beginning persistence training much sooner (before the levelling off of alpha strength evident in a comparison between Sessions 2 and 3 ACQ trials), it appears, due to the literature relating overlearning to increased retention, to be an unlikely explanation of the present results.

It would be interesting to discover whether subjects receiving the DFB trials during persistence training gain in discriminative ability. Clemens (1976) and Staudenmayer, et al. (1976) showed that subjects who could respectively discriminate heart rate and EMG would show transfer to a no-feedback condition. A simple test of the hypothesis could be made by including TRA probes among the persistence training trials, to see if subjects with included DFB trials learned better discrimination. Positive results would support the notion that PER trained subjects learned to pay more attention to internal cues, thus allowing for better discrimination.

The persistence training was begun at a rather arbitrary time, according to the best predictions which could be made from pilot data. It would be interesting to design a study in which one group receives alternating ACQ, DFB, and NFB trials from the start, and another ACQ and NFB, with DFB introduced later as in the present research.

Persistence training was initiated with already trained subjects in the present study because it was believed that subjects already having established endofeedback references and discriminative abilities would be more able to transfer dependency from the external feedback source to an internal one. This could be tested by making the above comparison, and testing for persistence.

Persistence training is a laboratory training method for increasing the maintenance of a trained response over time. It contrasts with the approach taken by other researchers interested in transfer of control, as their procedures involve collateral outside-the-lab practice (Budzynski, 1973; Green, et. al., 1970). While it is possible that PER training facilitates generalization of the response, specific laboratory-based procedures might be developed to focus on learned generalization. For example, increasingly complex stimulus situations could become a part of the training environment, after some initial enhancement had been demonstrated. This is not necessarily a better training approach for clinical populations than home practice, but might be used in conjunction with it. It is, like persistence training in the laboratory, worthy of further investigation, including possible applications in the clinic for alpha and other physiological activities. To the extent that therapeutic benefit is based upon actual changes in the trained physiological functions, expected

benefits for persistence and generalization training might include more efficient and effective therapy, with reduced frequency of follow-up appointments.

Other Issues

Little attention is ordinarily paid to the periods between training trials, which are often used as rest periods. In the present research, evidence was presented that between-trials probe activity could affect the amount of enhancement during feedback training. Subjects were required to (a) practice the alpha response, (b) maintain awareness of the alpha response, or (c) "rest" by looking through a book of attractive landscapes. The resting task may be functionally different from a nonstructured rest as used by Kamiya (1969), in that it lessens the likelihood that subjects could attend to or practice alpha. The fact that subjects who practiced the response did better on the feedback training ACQ task than other subjects, who were not significantly different from each other, suggests that the conventional wisdom of the between-trials rest period may be questionable. It would be interesting to compare the enhancement data from two groups of trainees, one of which would receive alternating ACQ and NFB trials, and the other continuous ACQ. It would also be wise to include a group which received alternating ACQ and rest periods, in order to replicate the findings of the present study. It is

conceivable that the subjects who are required to do the NFB task would show greater enhancement than the subjects in the other groups, as they performed so well in the present study.

The present research yielded enhancement across groups of 34.4% for Session 1, 65.7% for Session 2, and 66.5% for Session 3. Since baseline scores varied by less than five percent across sessions, the enhancement differences reflect alpha strength during feedback rather than variable baseline activity. The scores for the final two sessions were almost equal, suggesting either that subjects reached maximum or that they had achieved a plateau level in their training. A plateau might be achieved as a natural aspect of alpha training. Hardt (1975b) noted a similar effect occurring at several points during training, the first instance of which corresponds fairly well with the amount of training received in the present study. It is also possible that plateaus might be avoided or minimized by employing optimum training methodologies. Length of trials and sessions, experimental conditions, eye instructions, and transfer function relating cortical activity to feedback might optimally require alteration as the subject progresses in alpha training. Neither the present research nor Hardt's was designed to speak directly to this possibility.

An examination of other eyes-open alpha enhancement

results reported using integrated alpha as a dependent measure reveals maximum enhancement of 25% (Plotkin, 1976a) and an estimate of 20% (Travis, et al., 1974b). These values are considerably less than the enhancement obtained in the present research. Plotkin provided only six three-minute enhancement trials with lights on (and eyes open). These trials were partly randomized among an equal number of suppression and rest trials. Subjects were required, therefore, to learn two operations (enhance and suppress), with very brief trials totalling only eighteen minutes. These conditions would reasonably predict lesser enhancement, as the subjects in the present research were given eight nine-minute and one five-minute enhancement trials, with no suppression training (possible interference). Also, subjects who had a "rest" period (CON group) between training trials showed less enhancement than the other subjects.

It is difficult to assess the amount of enhancement shown by the Travis et al. subjects, as means are not reported. There were ten five-minute training trials, and subjects were requested to rest between trials. Data were reported as "change scores", which were based upon the number of integrator resets, as in the present study. The authors do not, however, state to which activity the change is relative. Assuming that the changes were relative to eyes-open baseline, the results become comparable to those

of the present study. Scores relative to baseline are, however, very subject to influence by baseline recording techniques, particularly the instructions given to subjects and the timing of the baselines. Such scores are helpful in limiting the heterogeneity of performance levels, thus making for simpler and more meaningful statistical analyses. Plotkin (1976a) has made a similar point. It is possible that the baseline techniques used in the present research and those used by Travis, et al., who did not report theirs, were different.

Conclusions

From the present research emerges a view of eyes-open alpha enhancement in which trainees use the feedback signal to produce increased alpha strengths, and also learn to discriminate high from low amounts of alpha in the ongoing EEG. Trainees also develop the ability to produce increased alpha independent from the presence of external feedback. Persistence of the trained response over time could be greatly enhanced by a specific ("persistence training") procedure which includes combining delayed feedback trials with the standard biofeedback trials.

While the present research does not address some of the issues, such as therapeutic value and experiential correlates of alpha, which have led to the popularity and

been the core of the controversy surrounding alpha biofeedback, it does provide strong evidence that alpha enhancement can be learned through biofeedback training, that trainees can continue to enhance alpha without feedback, and that the parameters of the feedback situation can be manipulated to provide different levels of enhancement and persistence after the termination of training. These findings provide a substantial foundation upon which an investigation of the applications of alpha training can be built.

References

Amsel, A. Behavioral habituation, counterconditioning, and a general theory of persistence. In A. Black & W. Prokasy (Eds.), Classical conditioning II: Current research and theory. New York: Appleton-Century-Crofts, 1972.

Beatty, J. Similar effects of feedback signals and instructional information on EEG activity. Physiology and Behavior, 1972, 9, 151-154.

Bergman, J. S., & Johnson, H. J. The effects of instructional set and autonomic perception on cardiac control. Psychophysiology, 1971, 8, 180-190.

Bergman, J. S., & Johnson, H. J. Sources of information which affect training and raising of heart rate. Psychophysiology, 1972, 9, 30-39.

Bilodeau, E. A., & Bilodeau, I. M. Variation of temporal intervals among critical events in five studies of knowledge of results. Journal of Experimental Psychology, 1958, 55, 603-612.

Blanchard, E. B., Young, L. D., & McLeod, P. Awareness of heart activity and self-control of heart rate. Psychophysiology, 1972, 9, 63-68.

Brackbill, Y., & Kappy, M. S. Delay of reinforcement and retention. Journal of Comparative and Physiological Psychology, 1962, 55, 14-18.

Brener , J. A general model of voluntary control applied to the phenomena of learned cardiovascular change. In P. A. Obirst, A. H. Black, J. Brener, & L. V. DiCara (Eds.) Cardiovascular physiology. Chicago: Aldine, 1974. (a)

Brener, J. Factors influencing the specificity of voluntary cardiovascular control. In L. V. DiCara (Ed.) Limbic and autonomic nervous system research. New York: Plenum, 1974. (b)

Brener, J., & Jones, J. M. Interoceptive discrimination in intact humans: Detection of cardiac activity. Physiology and Behavior, 1974, 13, 763-767.

Brown, B. B. Recognition of aspects of consciousness through association with EEG alpha activity represented by a light signal. Psychophysiology, 1970, 6, 442-452.

Brown, B. B. Awareness of EEG-subjective activity relationships detected within a closed feedback system. Psychophysiology, 1971, 7, 451-464.

Budzynski, T. H. Biofeedback procedures in the clinic. Seminars in Psychiatry, 1973, 5, 537-547.

Church, R. M. Systematic effects of random error in the yoked control design. Psychological Bulletin, 1964, 62, 122-131.

Cleeland, C. S., Booker, H. E., & Hosokawa, K. Alpha enhancement: Due to feedback or the nature of the task. Psychophysiology, 1971, 8, 262-263.

Clemens, W. J. Heart beat discrimination and the learning and transfer of voluntary heart rate control. Paper presented at the meeting of the Southern Psychological Association, New Orleans, March 1976.

Clemens, W. J., & MacDonald, D. F. The relationship between heart beat discrimination and heart rate control. Paper presented at the meeting of the Society for Psychophysiological Research, Toronto, October 1975.

DiCara, L. V. Introduction. In L. V. DiCara, T. X. Barber, J. Kamiya, N. E. Miller, D. Shapiro, & J. Stoyva (Eds.) Biofeedback and self-control 1974. Chicago: Aldine, 1975.

Diekhoff, G. M. Effects of feedback in a forced-choice GSR detection task. Psychophysiology, 1976, 13, 22-26.

Donin, J. A., Surridge, C. T., & Amsel, A. Extinction following partial delay of reward with immediate continuous reward interpolated at 24-hour intervals. Journal of Experimental Psychology, 1967, 74, 50-53.

Epstein, L. H., & Stein, D. B. Feedback-influenced heart rate discrimination. Journal of Abnormal Psychology, 1974, 83, 585-588.

Fitts, P. M., & Posner, M. I. Human performance. Belmont, California: Brooks/Cole, 1967.

Green, E. E., Green, A. M., & Walters, E. D. Voluntary control of internal states: Psychological and physiological. Journal of Transpersonal Psychology, 1970, 2, 1-26.

Hardt, J. V. EEG alpha learning: State of the art. Discussion of paper session at the meeting of the

Biofeedback Research Society, Monterey, California, February 1975. (a)

Hardt, J. V. The ups and downs of learning alpha feedback. Paper presented at the meeting of the Biofeedback Research Society, Monterey, California, Feburary 1975. (b)

Hardt, J. V., & Kamiya, J. Conflicting results in EEG alpha feedback studies: Why amplitude integration should replace percent time. Biofeedback and Self -Regulation, 1976, 1, 63-75. (a)

Hardt, J. V., & Kamiya, J. Some comments on Plotkin's self-regulation of electroencephalographic alpha. Journal of Experimental Psychology: General, 1976, 105, 100-108. (b)

Hart, J. T. Autocontrol of EEG alpha. Psychophysiology, 1968, 4, 506. (Abstract)

Jenkens, W. O., & Stanley, J. C. Jr. Partial reinforcement: A review and critique. Psychological Bulletin, 1950, 47, 193-234.

Jones, R. T., & Kazdin, A. E. Programming response maintenance after withdrawing token reinforcement. Behavior Therapy, 1975, 6, 153-164.

Kamiya, J. Conditional discrimination of the EEG alpha rhythm in humans. Paper presented at the meeting of the Western Psychological Association, San Francisco, April 1962.

Kamiya, J. Conscious control of brain waves. Psychology Today, 1968, 1, 55-60.

Kamiya, J. Operant control of the EEG alpha rhythm and some of its reported effects on consciousness. In C. Tart (Ed.), Altered states of consciousness. New York: Wiley, 1969.

Kamiya, J. Autoregulation of the EEG alpha rhythm: A program for the study of consciousness. In M. H. Chase (Ed.), Perspectives in the brain sciences. Los Angeles: University of California Brain Research Institute, 1974.

Kazdin, A. E., & Polster, R. Intermittent token reinforcement and response maintenance in extinction. Behavior Therapy, 1973, 4, 386-391.

Kinsman, R. A., O'Banion, K., Robinson, S., & Staudenmayer, H. Continuous biofeedback and discrete posttrial verbal feedback. Psychophysiology, 1975, 12, 30-35.

Kondo, C. Y., Travis, T. A., & Knott, J. R. The effects of changes in motivation on alpha enhancement. Psychophysiology, 1975, 12, 388-389.

Legewie, H. Subjective correlates of EEG feedback: Discrimination learning or superstition? Paper presented at the meeting of the Biofeedback Research Society, Monterey, California, February 1975.

Leibrecht, B. C., Lloyd, A. J., & Pounder, S. Auditory feedback and conditioning of the single motor unit. Psychophysiology, 1973, 10, 1-7.

Lewis, D. J., & Duncan, C. P. Effect of different percentages of money reward on extinction of a lever pulling response. Journal of Experimental Psychology, 1956, 52, 23-27.

Lovibond, S. H., & Caddy, G. Discriminated aversive control in the moderation of alcoholics' drinking behavior. Behavior Therapy, 1970, 1, 437-444.

Lynch, J. J., & Paskewitz, D. A. On the mechanisms of the feedback control of human brain wave activity. Journal of Nervous and Mental Diseases, 1971, 153, 205-217.

Lynch, J. J.,, Paskewitz, D. A., & Orne, M. T. Some factors in the feedback control of human alpha rhythm. Psychosomatic Medicine, 1974, 36, 399-410.

McFarland, R. A. Heart rate perception and heart rate control. Psychophysiology, 1975, 12, 402-405.

Morrell, L. K. Some characteristics of stimulus-provoked alpha activity. Electroencephalography and Clinical Neurophysiology, 1966, 21, 552-561.

Mulholland, T. Objective EEG methods for studying covert shifts of visual attention. In F. J. McGuigan & R. A. Schoonover (Eds.), The psychophysiology of thinking. New York: Academic Press, 1973.

Mulholland, T., & Evans, C. R. Oculomotor functions and the alpha activation cycle. Nature, 1966, 211, 1278-1279.

Nowlis, D. P., & Kamiya, J. The control of electroencephalographic alpha rhythms through auditory feedback and the associated mental activity.

Psychophysiology, 1970, 6, 476-484.

Peper, E. Feedback regulation of the alpha electroencephalogram activity through control of the internal and external parameters. Kybernetic, 1970, 7, 107-112.

Plotkin, W. B. On the self-regulation of occipital alpha rhythm: Control strategies, states of consciousness, and the role of physiological feedback. Journal of Experimental Psychology: General, 1976, 105, 66-99. (a)

Plotkin, W. B. Appraising the ephemeral "alpha phenomenon": A reply to Hardt and Kamiya. Journal of Experimental Psychology: General, 1976, 105, 109-121. (b)

Rosenthal, R., & Rosnow, R. (Eds.) Artifact in behavioral research. New York: Academic Press, 1969.

Rouse, L., Peterson, J., & Shapiro, G. EEG alpha entrainment reaction within the biofeedback setting and some possible effects on epilepsy. Physiological Psychology, 1975, 3, 113-122.

Schultz, J., & Luthe, W. Autogenic training. New York: Grune & Stratton, 1959.

Selzer, F. A., & Fehmi, L. G. Effects of rhythmical auditory signals on the electroencephalogram. Paper presented at the meeting of the biofeedback Research Society, Monterey, California, February 1975.

Shanab, M. E., & Ferrell, H. J. Transfer between downshift in reward magnitude and continuous delay of reward. Learning and Motivation, 1975, 6, 241-252.

Silverstein, S. J., Nathan, D. E., & Taylor, H. A. Blood alcohol level estimation and controlled drinking by chronic alcoholics. Behavior Therapy, 1974, 5, 1-15.

Skinner, B. F. The Behavior of Organisms. New York: Appleton-Century-Crofts, 1938.

Skinner, B. F. Are theories of learning necessary? Psychological Bulletin, 1950, 57, 193-216.

Staudenmayer, H., & Kinsman, R. A. Awareness during electromyographic biofeedback: Of signal or process? Biofeedback and Self-Regulation, 1976, 1, in press.

Staudenmayer, H., Kinsman, R. A, & Yaroush, R. A. Post-training transfer of awareness in EMG biofeedback

training. Paper presented at the meeting of the Biofeedback Research Society, Colorado Springs, February 1976.

Stern, R. M. Detection of one's own spontaneous GSR's. Psychonomic Science, 1972, 29, 354-356.

Strayer, F. F. Lateral eye-movements as an index of alpha enhancement with auditory feedback. Masters thesis, Simon Fraser University, September 1970.

Travis, T. A., Kondo, C. Y., & Knott, J. R. Alpha conditioning: A controlled study. Journal of Nervous and Mental Disease, 1974, 158, 163-173. (a)

Travis, T. A., Kondo, C. Y., & Knott, J. R. Parameters of eyes-closed alpha enhancement. Psychophysiology, 1974, 674-681. (b)

Valle, R. S., & Levine, J. M. Expectation effects in alpha wave control. Psychophysiology, 1975, 12, 306-309.

Walsh, D. H. Interactive effects of alpha feedback and instructional set on subjective state. Psychophysiology, 1974, 11, 428-435.

Appendix

The purpose of this section is to provide a brief review of some basic experimental conditions which need to be understood in order to meaningfully interpret and compare the results of alpha biofeedback research. The definition of the response is affected by the electrode configuration, eye instructions, and quantification of the response. The nature of the self-regulation task is affected by the experimental environment, the type of feedback provided, and the arrangement of training sessions and trials within sessions.

Two important issues in the discussion of electrode placement are the number of electrodes employed and their locations on the scalp. Most alpha research has named "occipital alpha" as the response of interest, but researchers have defined this in different ways. Perhaps most common has been a single midline occipital placement (monopolar), referred to one or both ears or mastoids as ground. Other researchers have taken occipital to frontal bipolar activity (Nowlis & Kamiya, 1970; Plotkin, 1967a) or occipital to parietal bipolar activity (Mulholland, 1968; Walsh, 1974). Hardt and Kamiya (1976b) have reasonably stated that the "occipital alpha" designation should be reserved for exclusively occipital placements. Thus,

bipolar placements with one occipital and one non-occipital placement could logically be named just as well by the non-occipital location. As alpha is usually seen most strongly in the occipital regions, it may dominate the alpha from another region in the EEG record. Nothing is gained, however, in applying the occipital alpha label to EEGs recorded from non-occipital locations. The empirical significance of electrode placement and configuration for biofeedback training of alpha enhancement has not been systematically investigated, and there is no reason to assume that results of research using different recording techniques would be comparable in all respects.

The present research monitors alpha from bipolar occipital to frontal right hemisphere placements, the same configuration used by Nowlis and Kamiya (1970) and Plotkin (1976a). While Hardt and Kamiya (1976b) are of the opinion that the frontal placement might be subject to eye movements, Plotkin (1976b) stated that "the F4 placement is sufficiently far back on the scalp to avoid the large eye artifacts that Hardt and Kamiya mentioned" (p. 114).

Eye instructions are important in alpha research because eyes-open and eyes-closed alpha may be two functionally different responses whose separate acquisitions are unrelated (Travis, et al., 1974b). Since eyes-open alpha usually shows more rapid enhancement and also

minimizes the possibility of drowsiness, it was judged to be more suitable for the present research. It should be noted that results might not generalize to the eyes-closed response, though the methodology used here would be excellent for a separate investigation of the eyes-closed response.

Most of the early alpha research quantified alpha as a percent time measure. Some arbitrary threshhold, or one related to the subject's resting level of alpha, was selected, and alpha was measured by the percentage of time it exceeded this threshhold. If the threshhold were fifteen microvolts, then alpha of twenty microvolts and alpha of one hundred microvolts would be scored the same - both as alpha present. This measure, also called criterion alpha, is bounded below by 0% and above by 100%.

Recent research (Hardt & Kamiya, 1976a); Travis, et al., 1974b) has established that an integrated amplitude measure, that is, the area under the voltage curve, is a more adequate measure of alpha for research purposes. This latter measure is referred to as "alpha strength", and unlike the percent time measure, has no upper bound. The present research quantifies alpha by integrating the entire alpha band (8-13 Hz) with no threshhold of minimum activity.

Most alpha biofeedback research is conducted in a quiet labrotory environment, shielded from electrical interference

and noise. In the present research, this semi sensory deprivation type environment is established, with the participants seated in a comfortable padded chair. It is likely that the simplicity of the environment is more important in eyes-open than in eyes-closed conditions, due to the possibility that subjects can control alpha by focusing and defocusing (Mulholland, 1973). While the isolation chamber setting developed as a part of the standard biofeedback procedure largely due to the environmental insulation required by older equipment, it quite likely contributes to the phenomenon under investigation (particularly experiential or therapeutic correlates of control).

A feedback signal can be either discrete or continuous and either proportional or binary. A continuous feedback signal is always present, and changes in intensity or frequency with changing alpha activity. This holds for visual, vibrotactile, and auditory feedback. Discrete feedback is not always available, but is given periodically, perhaps as a digital counter readout or verbal post-trial score. Binary feedback can signal only two levels of activity, such as present/absent or high/low, while proportional feedback provides a signal which reflects many levels of the monitored activity. The present research employs a continuous, proportional feedback tone. There is no on/off of the feedback to require orientation, and the

analog signal contains more information than a binary one.

There has been no research which systematically compares different arrangements of training periods, either over separate sessions or days or over trials within sessions. Hardt (1975) presented evidence that the first stage of alpha feedback training, an adaptation and habituation phase lasting about two hours of training time, is qualitatively different from subsequent actual alpha enhancement. The majority of research, however, provides only for brief (less than two hours) training, with trials spread over sessions or all within a single session. Often sessions include rest periods or suppression training, as well as alpha enhancement training. There has been no empirical evidence favoring any particular arrangement of training trials, but as Hardt and Kamiya (1976b) state, it is likely that very short trials would not be conducive to biofeedback assisted learning.

The present research spread training sessions over several days, and employed trials of moderate length separated by other instructed tasks without feedback.